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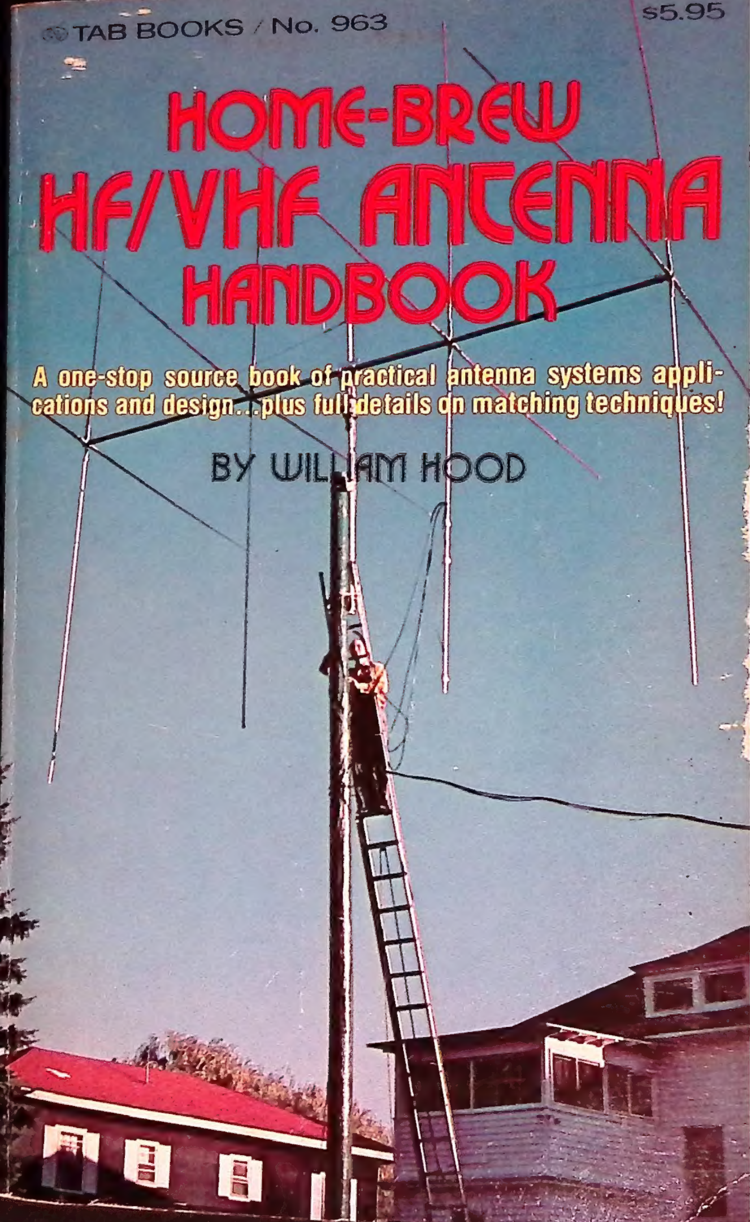
# HOME-BREW HF/VHF ANTENNA HANDBOOK

**A one-stop source book of practical antenna systems applications and design...plus full details on matching techniques!**

BY WILLIAM HOOD



# HOME-BREW
# HF/VHF ANTENNA
# HANDBOOK

# Dedication

This book is dedicated to the memory of Jim Walsh, W1MCR. A kindly old man whose patience and understanding at the Bunker Hill Boys' Club of Boston, Massachusetts, encouraged the author into the hobby that has provided many years of challenge and enjoyment, and opened the door to a vocation.

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TAB BOOKS
Blue Ridge Summit, Pa. 17214

FIRST EDITION

FIRST PRINTING—OCTOBER 1977



Printed in the United States
of America



Library ofCongress Cataloging in Publication Data

Hood, W Edmund.
Home-brew HF Flash VHF Antenna Handbook.

Includes index.
1.Radio--Antennas--Amateurs'manuals.I.Title.
TK9956.H457. 621. 3841'35 77-15138
ISBN 0-8306-7963-4
ISBN 0-8306-6963-9 pbk.

Cover photo courtesy Rev. Myron Jacob Kaufman, K2GAT

# About the Author

The author was first licensed WN1USM in 1952. He has worked professionally in the electronic field since 1956 and has published a number of articles in 73 and CQ magazines. He moved from his native Boston, Massachusetts, to the Rochester, New York, area in 1969, at which time he received his present call, W2FEZ.

Mr. Hood works for Scientific Radio Systems in Rochester, New York. He presently holds an Amateur Extra License and a First Class Commercial Radiotelephone License.

In this, the author's first major book, he brings you a compilation of his 25 years in amateur radio, most of which he gained the hard way.

# Preface

Many amateurs, especially those who are new to the field, spend hundreds of dollars on their equipment then put up the cheapest piece of wire available as an antenna. The futility of this becomes evident when we realize it is the antenna and the antenna alone that produces or captures a radio wave. The transmitter only supplies the antenna with the raw material from which to make radio waves; the receiver only processes the electrical impulses that the antenna produces.

Here is another way of looking at it. The antenna is to a radio station what microphones and loudspeakers are to audio equipment. You never see an audiophile buy a $500 hi-fi system and connect it to $3 speakers. Why, then, should we do this with antennas? It isn't nice to fool with Mother Nature. She has her rules and, when they're observed, she'll work for you.

This book is directed to the middle-of-the-road amateur. We do not intend to try to make you an engineer, nor do we assume that you are one. By the same token, we assume that the reader has some working knowledge of electronics.

Some of the information offered herein may be repeated in other chapters. We feel that this best supplies the reader with the needed information with a minimum of digging. Moreover, the first chapter is devoted entirely to the basic rules and formulas that are applied throughout the book. This we do for the convenience of the reader who, after getting his antenna

working, often needs to look up some principle or formula and does not wish to paw through the entire book. In most instances, if all you want is a general rule or formula, you'll find it in the first chapter.

We have tried to include material not only for the amateur, but also for the CBer and for the SWL. Generally speaking, antennas that work for transmitting also work well for receiving. However, there are some antennas that are better applied to receiving than to transmitting. The Windom, Beverage, and nonresonant-long-wire are examples of these types.

The author makes no pretext at being any kind of super wizard. Many people, especially those in the engineering end of electronics, may know of some favorite antennas not included in this book. Our intention here is to offer the benefits of a quarter-century of the author's experience so that you, the reader, might gain a better foothold on the last stand of amateur home-brew equipment.

William Hood, W2FEZ

# Contents

# Chapter 1
# Basic Principles and Formulas

Except for wavelength, radio waves are identical to light. They can be focused, reflected, refracted, and polarized. Because of the difference in wavelength, radio waves pass easily through some substances that block light but are, in all other respects, identical.

## WAVE PROPAGATION

A radio wave consists of an electric field and a magnetic field at right angles to one another as shown in Fig. 1-1. As the wave travels, the two fields change direction and intensity while maintaining their relationships to one another. Should these moving fields intercept an electric conductor, they would induce an alternating current in that conductor with a magnitude and polarity corresponding exactly to the magnitude and direction of the fields comprising the wave.

Radio waves travel at the speed of light: 299,793,077 meters per second, or 186,282.386 miles per second, in empty space. For convenience, we round off these figures to 300,000,000 meters and 186,000 miles per second. The distance a wave travels while making one complete cycle is called the wavelength. A complete cycle occurs when the two fields have undergone two complete reversals and returned to their starting point. Figure 1-2 shows a waveform with a cycle measured at a zero volt reference and at a positive voltage

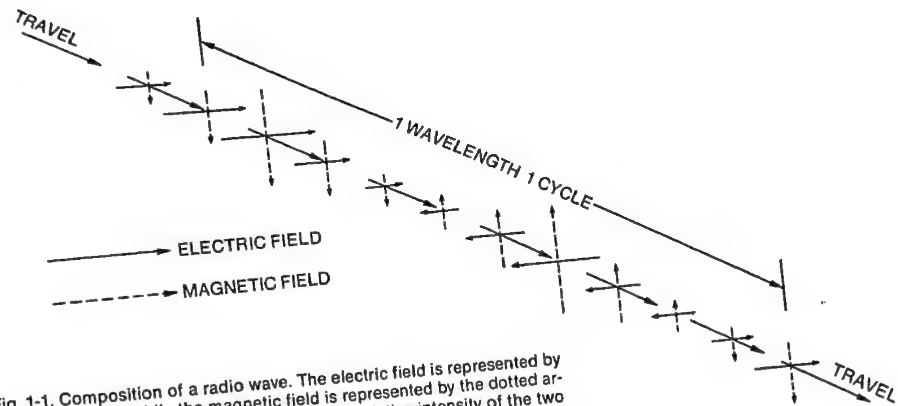



Fig. 1-1. Composition of a radio wave. The electric field is represented by the solid arrows, while the magnetic field is represented by the dotted arrows. The length of the arrows indicated the relative intensity of the two fields through various parts of a cycle. One complete cycle can be measured from any portion of the wave so long as measurement is made from the starting point to the next identical portion.

maximum. The number of waves passing in one second is called the frequency, expressed in hertz, kilohertz, or megahertz. A hertz is one cycle per second; a kilohertz one thousand; and a megahertz one million cycles per second.

Light travels in a straight line. If you light a candle, the base remains in shadow unless something reflects a light beam there. Similarly, a radio signal originating at any point on the earth's surface will not reach beyond the horizon unless something reflects it. Fortunately, nature has provided a reflector for high-frequency radio communication.

High above the surface of the earth are several layers of electrically charged particles collectively known as the ionosphere. Figure 1-3 shows the layers of interest to amateurs. These layers absorb waves of some frequencies and reflect waves of other frequencies. Variations in the particular frequencies affected and in the direction of reflection cause the various bands below 30 MHz to "open up" to different parts of the world from time to time.

Radio waves striking the ionosphere are reflected back to earth far from their point of origin (See Fig. 1-4). They can then be reflected back to the ionosphere and thence to earth again several times. The area between these skips, known as the skip zone, contains little or no signal.

One ordinarily would expect the signal to be radiated uniformly at all angles thereby covering the entire surface with signal. Unfortunately this doesn't happen. The reflecting ability of the ionosphere is not distributed evenly thus it supplies concentrated signals to some places while leaving others void of signals. Also, because of the reflectivity of the

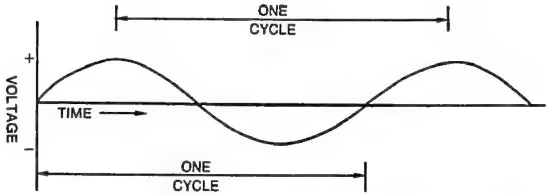



Fig. 1-2. Voltage wave set up in an antenna by a passing radio wave. Again note that one cycle is the time between any two points at which the magnitude and polarity of the voltage is identical.

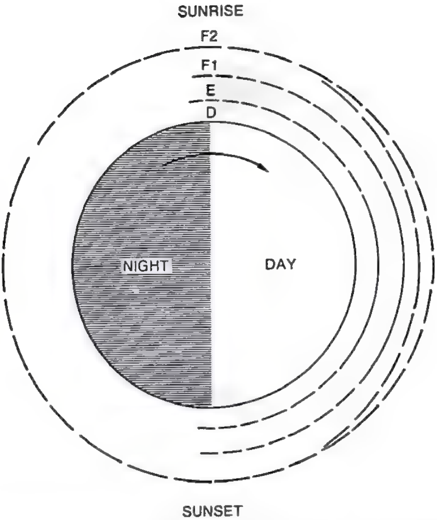


Fig. 1-3. The layers of the ionosphere. Continuity of the lines indicates the relative density of the layers. Note that only the F layer is present for a full 24 hours.

ground, antennas tend to bounce their radiation at particular angles. High-angle radiation is best for communications from a few hundred miles to a thousand miles or so, while low-angle radiation brings in remote places.

A portion of the signal, known as the ground wave, follows the surface of the earth to just beyond the visible horizon. Beyond that range, if there are no signals being reflected back from the ionosphere, is a dead zone. Thus it is possible to hear stations hundreds of miles away while stations just a few miles away are received very poorly.

There are four layers of the ionosphere of particular concern to amateurs, labeled D, E, F1, and F2. The D layer, which only exists in the daytime, does little reflecting but absorbs signals, especially around midday when ionization is greatest. It is the nightly disappearance of this layer that makes the 80- and 40-meter bands open up at night. The E layer is responsible for some medium-distance propagation, but when ionization is high it can also absorb signals. It thins out

just after sunset and makes a fast comeback the next morning. The F layer is the most stable of all, owing its stability to its height. It remains effective at night, although moving to a greater height, becomes weakest just before sunrise, and then stages a fast comeback. During periods of high ionization, it divides into the F1 and F2 layers. The lower of the two, the F1 layer, is similar to the E layer in its behavior, and does some absorbing. The F2 layer remains a useful reflector for daytime communications.

The particular frequencies absorbed or reflected, and the extent of absorbtion or reflection, is governed by the amount of ionization of the various layers. Ionization is caused by solar radiation, and consequently long-distance communications respond markedly to the 11-year sunspot cycle. The 20-, 15-, and 10-meter bands are comparatively dead during sunspot lull periods but distant stations come rolling in on these bands during peak activity periods.

From all this, we can see that, for long-distance communication, there exists upper and lower usable frequencies for communicating with various parts of the world. These frequencies vary with time of day, season, and period in the sunspot cycle. Government forecasts of radio propagation conditions are published regularly for most amateur bands, and by studying them an amateur can enhance his efforts for DX operation.

## TUNED CIRCUITS

When an alternating voltage is imposed across a capacitor, current will begin to flow as the capacitor charges during the first half cycle. During the second half cycle the

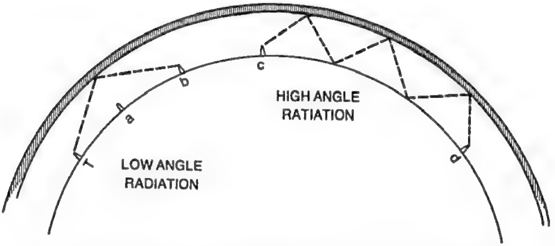



Fig. 1-4. How the ionosphere reflects signals over the horizon.

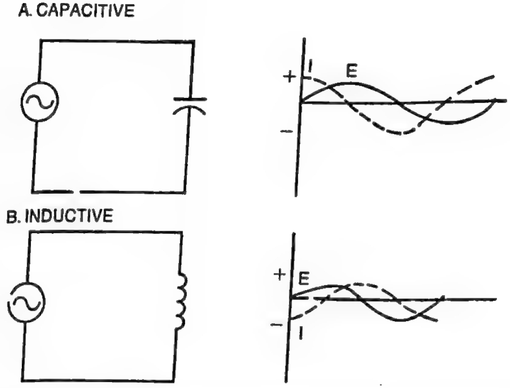



Fig. 1-5. Voltage and current relationships for pure capacitive and pure inductive circuits. With capacitance, current leads voltage by 90°. With inductance, current lags voltage by 90°.

capacitor will discharge back into the source and then charge with opposite polarity. The instant of maximum current is at the start of the half-cycle, not at the instant of maximum voltage. Thus current does flow through the capacitor, but the current sine wave is a quarter cycle ahead of the voltage sine wave—that is, 90° out of phase. Figure 1-5A shows this relationship.

When an alternating voltage is imposed across an inductor current tries to flow, but is opposed by the electromagnetic effect of the inductor. By the time the current flow reaches maximum, the voltage waveform has reached a node. Thus current flows through an inductor, but lags behind the voltage wave by a quarter cycle, as shown in Fig. 1-5B. Again the current is 90° out of phase with the voltage, but in the opposite direction.

Now consider the situation in which an inductor and a capacitor are shunted together in a parallel-tuned circuit. Current flows through both, but one is 180° out of phase with the other. The two currents combine mathematically to result in a current equal to the mathematical difference, with the phase of the larger. We now begin to see that, if the two currents are equal to one another, that is, if the capacitive reactance equals the inductive reactance, something special

happens. When the reactances are equal, the inductive current exactly cancels out the capacitive current so that no current flows (See Fig. 1-6). A situation in which voltage is present with little or no current is, by Ohm's Law, a very high resistance or, in the terminology of alternating current, a very high impedance.

Finally, imagine a circuit in which the inductor and the capacitor are in series. If, in a given instance, the current flows first through the capacitor, it will lead the voltage by 90°. Then as it flows through the inductor, the already-leading current will be caused to lag 90° from where it is, putting it into phase with the voltage. When the voltage is in-phase with the current, all that then affects it is the DC resistance of the circuit. Thus a series-tuned circuit offers a very low impedance at resonance.

The above situations have been described for circuits in which there is no DC resistance, only the inductive or capacitive reactance. Such circuits are nonexistent; some DC resistance is always present. When reactance and resistance

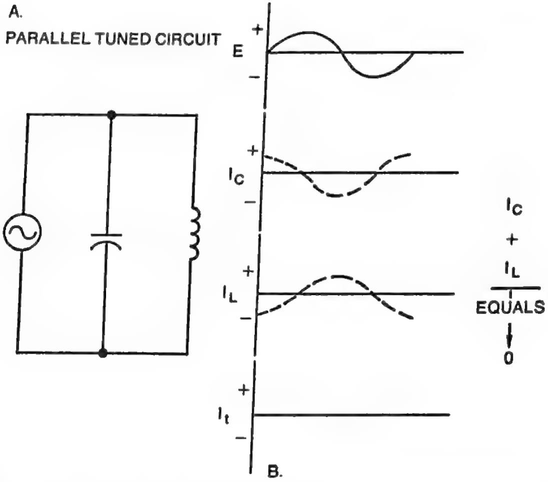



Fig. 1-6. Parallel tuned circuit. Equal and opposite currents are shown flowing through the coil and the capacitor. They cancel each other out so that their sum total is zero current.

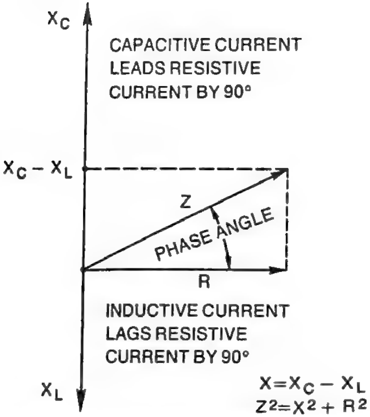



Fig. 1-7. In a circuit having inductance, capacitance, and resistance the impedance is a composite of the three. The circuit represented by this diagram is nonresonant, as indicated by the net capacitive reactive remaining.

combine in an AC circuit they do not add to one another arithmetically, but rather they add as if they were two sides of a right triangle—the impedance of the circuit would be the hypotenuse (See Fig 1-7). At resonance the reactances combine to cancel one another leaving, in a series tuned circuit, only the DC resistance. In a parallel-tuned circuit the reactive currents add in the same manner as the reactances in a series-tuned circuit. Consequently, a series-tuned circuit has an impedance equal to the DC resistance at resonance, and a parallel-tuned circuit has an equivalent parallel resistance equal to the Q of the circuit multiplied by the inductive reactance.

This figure of merit, Q, is a measure of the relative efficiency of an inductor, and is determined partly by the ratio of inductive reactance to the DC resistance. In a tuned circuit, the relative bandwidth is determined by dividing the resonant frequency by the Q. Figure 1-8 represents this relationship.

### The Antenna as a Tuned Circuit

An antenna is a resonant device and, since the voltage and current within it is 90° out of phase, it can be made to behave,

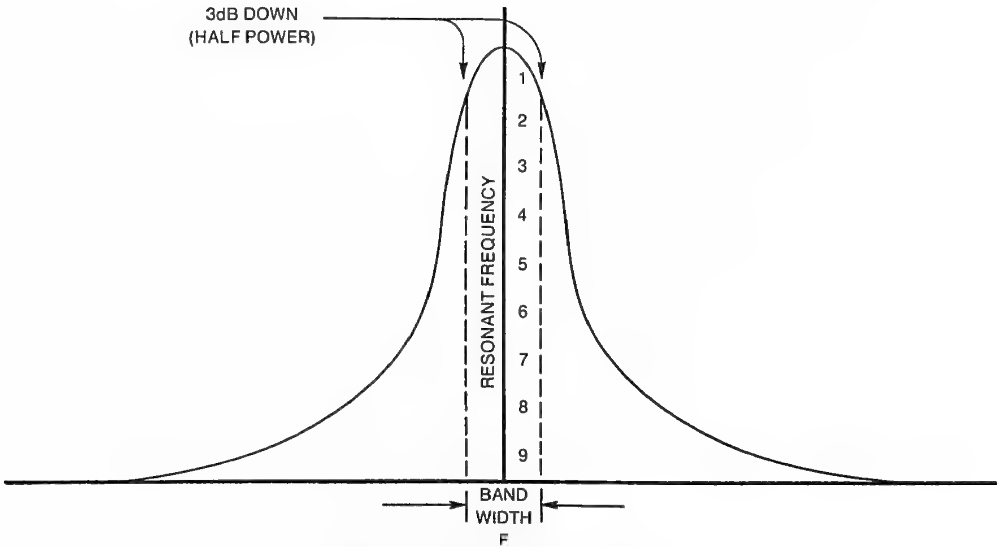



Fig. 1-8. Typical curve of a resonant circuit.

in some respects, as a tuned circuit. It differs from a conventional tuned circuit in that it will resonate at more than one frequency. Fed at the end, an antenna has a very low impedance to all frequencies at which it is an odd number of quarter-wavelengths long, and a high impedance to all frequencies at which it is an even number of quarter-wavelengths long. Fed in the center, an antenna offers a low impedance to all frequencies at which it is an odd number of half-wavelengths long, and a high impedance to all frequencies at which it is an even number of half-wavelengths long. If the feed-point is moved off center, as in a Windom antenna, impedance is proportional to a function of the tangent, based on the number of electrical degrees the feed-point is from the center of the antenna.

**Rules and Formulas**

Radio signals are propagated around the world by:

- Reflection back to earth by the ionosphere
- Bending and reflection by the troposphere (This generally affects signals above 30 MHz.)
- Atmospheric ducts (Further discussed with VHF antennas.)
- Aurora (Frequencies below 30 MHz become "dead"; higher frequencies open up for long-distance communications.)

Ionospheric propagation varies in intensity with the 11-year cycle of sunspots, and affects the amateur bands as follows:

- 160 meters: Reliable daytime band for short-range communications (100 miles or so) day and night. Opens up a little more at night, especially in the winter.
- 80 meters: All right for ranges of 200 miles or so during the day. Better in winter than in summer. Much static on summer afternoons. Nighttime opens up for several thousand miles. Transoceanic operation possible in winter, especially during sunspot peaks.
- 40 meters: Similar to 80, but greater distances possible. Up to a thousand miles or more is possible during the day, with ranges halfway around the world

at night. Morning conditions bring out the minimum interferance from European broadcast stations. Much less summer daytime static, except in tropical areas.

- 20 meters: One of the best DX bands. Open around the world 24 hours during sunspot peaks. During sunspot lull periods it is dead at night.
- 15 meters: Excellent DX band. More variable than 20, especially during sunspot lull periods, when it "dies" at night, except for occasional sporadic openings. During sunspot peaks, it can be open 24 hours to all parts of the world.
- 10 meters: Generally dead during sunspot lull periods, except for local work. During sunspot peaks, is considered a good daytime DX band, and communications over moderate distances are possible at night.
- 6 meters: We are now getting to the borderline frequencies for ionospheric propagation. DX can be worked during the very peak of the sunspot cycle. Generally offers ranges of one or two thousand miles during sunspot lull periods. Otherwise good for local work.
- 2 meters: Best as a local band. FM operation is very popular. Relatively little ionospheric effects. Interesting tropospheric propagation for the experimenter.
- Above 2 meters: More experimenting done here than in the lower bands. Considerable FM repeater work on 220- and 420-MHz. Tropospheric propagation and atmospheric ducts give interesting results. In the bands above 420 MHz, frequency stability becomes a problem, and communication is generally line-of-sight.

Alternating current and phenomena caused by it are rotating functions. The basic AC generator is a rotating device. Consequently, alternating current devices behave subject to many of the mathematical laws governing circular and angular functions. Each cycle of a wave consists of 360 degrees, and many of the formulas contain functions of pi.

The number pi is approximately:

3.14159 26535 89693 23846 26433 83279 50288
41971 69399 37510 . . .

Don't let the size of the number frighten you. For amateur use, three or four decimal places are plenty.

Radio waves travel at the speed of light. The speed of light in a vacuum is approximately:

186,282.386 miles per second
or
299,793,077 meters per second.

For amateur calculations, you can round these off to 186,000 miles per second and 300 million meters per second.

Except when affected by the atmosphere, radio waves travel in a straight line. That portion of the signal that is closest to the ground is called the ground wave. The portion that radiates at any appreciable angle above ground is called the sky wave. For direct (line-of-sight) communications, the distance to the radio horizon—including "bending" of the signal by the atmosphere, diffraction over the earth's surface, etc.—can be calculated by the formula,

$$D\,(\text{miles}) = 1.415\sqrt{H_t} + \sqrt{H_r}$$
$$D\,(\text{kilometers}) = 4.124\sqrt{H_t} + \sqrt{H_r}$$

$H_t$ is the height of the transmitting antenna, in feet for the miles formula, in meters for the kilometers formula. $H_r$ is the height of the receiving antenna, in feet for the miles formula, in meters for the kilometers formula.

The vast majority of antennas in use are based on a conductor one half wavelength long. Calculation of a half-wave antenna begins with the formula:

$$\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}}$$

Radio waves travel at the speed of light, which is 300,000,000 meters per second. Consequently,

$$\underset{(\text{meters})}{\text{Wavelength}} = \frac{300{,}000{,}000}{\text{Frequency in Hertz}}$$

If we express the frequency in megahertz, we can drop the six least-significant digits from the velocity figure (thus 300).

Remember also that we are looking for a half wavelength ($300 \div 2 = 150$). Now we have,

$$\underset{\text{(meters)}}{\text{1/2 Wavelength}} = \frac{150}{\text{Frequency in MHz}}$$

The conversion factor to convert meters to feet is 3.28. Consequently,

$$\underset{\text{(feet)}}{\text{1/2 wavelength}} = \frac{150 \times 3.28}{\text{Frequency in MHz}} = \frac{492}{\text{F in MHz}}$$

Electricity travels slightly slower in wire than in space. We therefore reduce the velocity factor by about 4.9% ($492 \times 0.049 = 468$), and we obtain,

$$\text{1/2 wave of wire} = \frac{468}{\text{Frequency in MHz}}$$

This is the basic antenna formula, giving a length directly in feet to cut a transmitting (or receiving) antenna that will be resonant, at the desired frequency. There are a couple of other factors affecting the calculation of half-wave antenna. Each type of wire has a slightly different velocity factor, and the feed-point impedance varies with both the height of the antenna and the conductivity of the ground beneath it. To obtain the best possible SWR, along with other improved characteristics, you will have to prune the antenna, that is trim it to the exact length required. For this reason, always cut an antenna to be pruned slightly longer than the length obtained from a formula.

Now that we have derived a convenient formula for calculating the length of a half-wave antenna, lets look at some characteristics of other types of antennas.

- The length of an inverted-vee antenna can be calculated from the formula:

$$\text{Length} = \frac{464}{\text{Frequency in MHz}}$$

- A half-wave dipole fed in the center has an impedance of approximately 72 ohms; a half-wave inverted vee

Table 1-1. Coaxial Cable Characteristics.

| TYPE | Z | MAX WATTS | | | LOSS IN Db/100 · | | | CAP/FT pF | VELOCITY FACTOR | DIAMETER |
|---|---|---|---|---|---|---|---|---|---|---|
| | | <30 MHz | 30-150 | >150 MHz | <30 MHz | 30-150 MHz | >150 MHz | | | |
| RG8U | 50 | 2kW | 1.5kW | 700 | 1 | 2 | 4.2 | 30 | 0.66 | 0.405 |
| RG11U | 75 | 1.8kW | 1.4kW | 600 | 0.94 | 1.9 | 3.8 | 20.5 | 0.66 | 0.405 |
| RG58U | 53 | 500 | 300 | 20 | 1.9 | 4.1 | 8 | 28.5 | 0.66 | 0.195 |
| RG59U | 75 | 600 | 500 | 200 | 1.9 | 3.8 | 7 | 21 | 0.66 | 0.242 |
| TVRG59U | 72 | 800 | 500 | 200 | 2 | 4 | 7 | 22 | 0.66 | 0.242 |

fed in the center has an impedance of approximately 50 ohms.

- A quarter-wave antenna fed at the end has an impedance of approximately 34 ohms.
- A quarter-wave ground-plane antenna with horizontal radials has an impedance of approximately 34 ohms.
- A quarter-wave ground-plane antenna with the radials angled down at 45° has an impedance of approximately 50 ohms.
- A half-wave folded dipole has an impedance of approximately 300 ohms.
- A Windom antenna, fed 14% off center has an impedance of approximately 600 ohms.

For efficient transfer of power, the source impedance must match that of the load, and both must be matched by the characteristic impedance of the transmission line. Refer to Table 1-1 for the characteristics of some common types of coaxial lines. If these conditions are not met, an antenna coupler or other matching device is necessary.

The characteristic impedance of coaxial line can be calculated from the formula:

$$Z = 138 \log \frac{D}{d} \text{ (for air-insulated line)}$$

Z = characteristic impedance in ohms
D = I.D. of outer conductor
D = O.D. of inner conductor

Diameters can be expressed either in inches or meters, but both must be in the same units.

The characteristic impedance of air-insulated parallel lines can be calculated from the formula:

$$Z = 276 \log \frac{D}{r}$$

Z is the impedance in ohms.
D is the center-to-center distance between the conductors.
r is the radius of the conductor.

As with the previous formula, D and r must be expressed in similar units, either inches or meters.

A length of transmission line cut to a quarter or a half wavelength and used as a tuned circuit is called a stub (Fig. 1-9). Some important characteristics are:

- A quarter-wave stub shorted at the end offers a high impedance to the resonant frequency and shorts out all others.
- A quarter-wave stub open at the end offers a short circuit to the resonant frequency and a high impedance to all other frequencies.
- A half-wave open stub behaves the same as a quarter-wave shorted stub.
- A half-wave shorted stub behaves the same as a quarter-wave open stub.

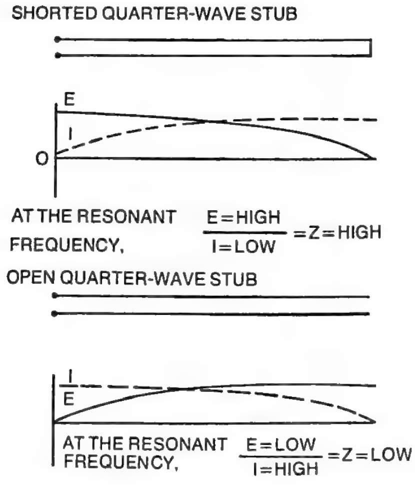



Fig. 1-9. Voltage and current distribution along a quarter-wave transmission line.

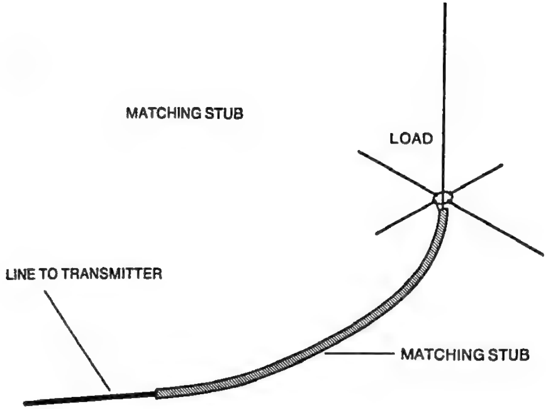



Fig. 1-10. Use of a quarter-wave section of line to match oddball combinations of line and load impedances.

A quarter-wavelength section of transmission line selected for its impedance can be used as an impedance transforming device by connecting it to the load as shown in Fig. 1-10. Note that the line must be a quarter-wavelength long. The formula for matching the impedance is:

$$Z = \sqrt{Z_s Z_l}$$

Z is the characteristic impedance required for the line.

$Z_s$ is the impedance of the source.

$Z_l$ is the load impedance.

As an example, a 34-ohm antenna and a 75-ohm transmitter output can be matched with a piece of 50-ohm line exactly a quarter-wave long.

Some other characteristics to remember about transmission lines and antennas are:

- A shorted section of line less than a quarter-wavelength long appears inductive.
- An open section of line less than a quarter-wavelength long appears capacitive.
- Any length of line terminated in a resistance equal to its characteristic impedance offers a purely resistive load and reflects no power back toward the source.

- An antenna slightly less than a multiple of quarter wavelengths long appears capacitive.
- An antenna slightly more than a multiple of quarter wavelengths long appears inductive.
- An inductive load is matched by adding capacity.
- A capacitive load is matched by adding inductance.

An inductor offers increasing reactance with increasing frequency. The formula for inductive reactance is:

$$X_L = 2\pi F L$$

$X_L$ is the reactance in ohms.
F is the frequency in megahertz.
L is the inductance in microhenries.

The figure-of-merit, or Q, of an inductor is given by the formula:

$$Q = \frac{X_L}{R}$$

Q is the figure of merit.
$X_L$ is the inductive reactance.
R is the equivalent parallel resistance.

A capacitor offers decreasing reactance with increasing frequency. The formula for capacitive reactance is:

$$X_c = \frac{1}{2\pi F C}$$

$X_c$ is the capacitive reactance in ohms.
F is the frequency in megahertz.
C is the capacity in microfarads (not picofarads).

The inductance of an air-core coil can be calculated by this formula:

$$L = \frac{0.2\, a^2\, n^2}{3a + 9b + 10c}$$

L is the inductance in microhenries.
a is the diameter of the coil in inches.
b is the length of the coil in inches.
c is the depth of the winding (Omit c for a single-layer coil).
n is the number of turns.

The capacitance of a capacitor can be calculated from the formula:

$$C = 0.0225K \frac{a}{s} (N-1)$$

C is in microfarads.
a is the area of one side of a plate. (If two size plates, use smaller.)
s is the space between the plates, or the thickness of the dielectric.
N is the number of plates.
K is the dielectric constant, as given below:

| | |
|---|---|
| Air | 1.0 |
| Bakelite | 4.4 to 5.4 |
| Window glass | 7.6 to 8 |
| Plexiglass | 2.8 |
| Polystyrene | 2.6 |
| Polyethylene | 2.3 |
| Acetate | 3.7 |
| Mica | 5.4 |
| Teflon | 2.0 |

A tuned circuit, consisting of an inductor and a capacitor, is resonant at the frequency at which the inductive and capacitive reactances are equal. Remember that current through an inductor leads the voltage by 90°; current through a capacitor lags the voltage by 90°. With either a perfect inductor or capacitor, current is drawn but no power is consumed.

Resonant frequency is calculated by the formula:

$$F = \frac{1}{2\pi\sqrt{LC}}$$

F is the frequency in megahertz.
L is the inductance in microhenries.
C is the capacity in picofarads.

The following formula can be solved to determine either inductance or capacity:

$$LC = \frac{25330}{F^2} \qquad L = \frac{25330}{F^2\,C} \qquad C = \frac{25330}{F^2\,L}$$

At resonance, a series-tuned circuit offers a very low impedance; a parallel-tuned circuit offers a very high impedance.

The impedance of a nonresonant series circuit is found by the formula:

$$Z = \sqrt{X^2 + R^2}$$

Z is the impedance in ohms.
X is the difference between the inductive and the capacitive reactance.
R is the DC resistance.

To find the impedance of a nonresonant parallel circuit, first combine the reactances with this formula:

$$X = \frac{-X_l X_c}{X_l - X_c}$$

$X_l$ is the inductive reactance.
$X_c$ is the capacitive reactance.

Then combine resistance and reactance in this formula:

$$Z = \frac{RX}{j\sqrt{R^2 + X^2}}$$

The relative strength of a radiated signal is inversely proportional to the square of the distance from the antenna. For example, If the signal strength is known at a given distance from the antenna, at twice the distance, the strength will be one fourth that at the reference point.

Relative signal strength is usually measured in decibels with respect to an established reference set up as 0 dB. The decibel equivalent of a voltage ratio measured across an identical impedance is:

$$dB = 20 \log \frac{E_2}{E_1}$$

The decibel equivalent of a power ratio measured across an identical impedance is:

$$dB = 10 \log \frac{P_2}{P_1}$$

Table 1-2. dB Equivalents.

| RATIO | dB POWER | dB VOLTAGE |
|---|---|---|
| 2:1 | 3 | 6 |
| 4:1 | 6 | 12 |
| 10:1 | 10 | 20 |
| 100:1 | 20 | 40 |

It is much easier to estimate decibels if the relationships in Table 1-2 are remembered.

There is no such thing as a perfect source of electrical energy. Every source, including a radio transmitter, has a certain amount of internal resistance or impedance which consumes some of the power generated. A little application of Ohm's Law with various combinations of load and source resistances will show that the greatest amount of power is delivered when the load resistance is the same as that of the source.

When radio frequency energy is involved, reactive properties in the source and load make the phenomenom far more complex. A certain amount of power is generated, and that which is not consumed by the load is reflected back to the source where it is dissipated in the form of heat. Not only must the source and the load be matched for an efficient power delivery, but also the transmission line characteristics must match or be matched to those of the source and load.

If there is a mismatch, either source-to-load or in transmission line characteristics, the reflected power causes the voltage and current to be unevenly distributed along the line, having maximum and minimum points at intervals coincident with the wavelength of the signal. The ratio between maximum and minimum levels is called the *standing wave ratio*, abbreviated SWR. The SWR can be used as a measurement of the overall behavior of an antenna system. It is measured with a reflected-power meter, or SWR bridge. A ratio less than 2:1 is considered acceptable; 1.5:1 or better is considered pretty good. An SWR of 1.0:1 exists only in theory, and anything approaching that is an indication of excellent performance.

Standing wave ratio is directly proportional to the amount of mismatch in a system. It can be calculated from the formula:

$$\text{SWR} = \frac{R}{r}$$

R is the larger of the two impedances, either source or load.
r is the smaller of the two impedances.

The reflection coefficient can be calculated from the formula:

$$C_r = \frac{R - r}{R + r}$$

r = source impedance
R = load impedance

A negative result of this formula merely indicates a reversal of phase.

The percentage of power being reflected back to the source may be found by squaring the reflection coefficient.

Example: Source = 50 ohms, load = 150 ohms.

$$\text{SWR} = \frac{150}{50} \text{ or } 3{:}1.$$

$$C_r = \frac{50 - 150}{50 + 150} = \frac{-100}{200} = -0.5 \text{ (note phase reversal)}$$

$$\text{Power reflected back} = (-0.5)^2 = 0.25, \text{ or } 25\%$$

# Chapter 2

# Basic Antennas, Materials, and Ground Systems

Although our discussion is directed toward the eventual use of an antenna for transmitting, the principles outlined here apply to receiving applications as well. While any piece of conductor will, of course, pick up *some* signals, maximum efficiency is realized only when the antenna is resonant. So far as transmitting is concerned, resonance in the antenna system is a must if damage to the equipment is to be avoided. Resonance can be achieved either by the natural dimensions of the antenna or by external tuning devices.

## THE ANTENNA AS A RESONANT DEVICE

Electricity travels through a conductor at close to the speed of light. When it reaches a discontinuity in the conductor, it is reflected back toward the source. If the current is alternating, and if a reflected current reaches the source, or feed-point, at the right instant, it is reinforced by succeeding cycles until relatively little energy is needed to maintain a standing wave on the antenna. The action compares to that of a swinging pendulum which is reinforced by a light push at exactly the right instant in each cycle of its swing. (See Fig. 2-1.)

Current enters the antenna (A) and moves from the feedpoint toward the ends (B). It reaches the end and, having nowhere to go to dissipate its energy, is reflected (C) back

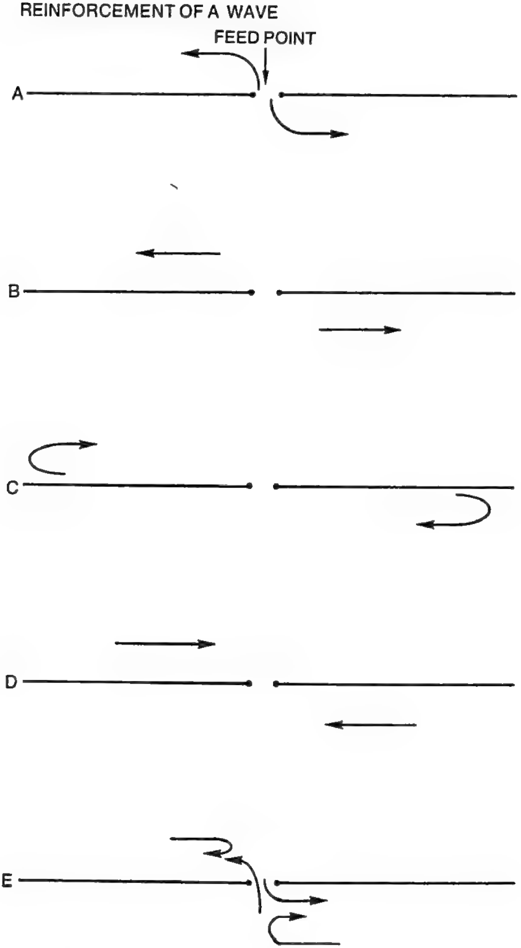



Fig. 2-1. A half-wave dipole used to show how current becomes reinforced with succeeding waves in a resonant antenna. A wave travels along the antenna (B), is reflected at the ends (C), travels back towards the feed point (D), where it is reinforced by the next wave entering the feed point.

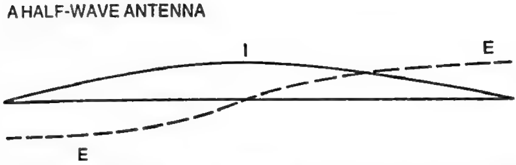



Fig. 2-2. Voltage and current distribution along a half-wave antenna. Observe the relative voltage and current levels at any point, then approximate impedance with Ohm's Law.

toward the source. It moves back toward the source (D) where the next cycle arrives at the exact instant to reinforce the first cycle (E). This continues ad infinitum so long as energy is fed to the antenna.

As with the swinging pendulum, the amount of push needed to maintain oscillation is least where the volume of current is greatest. Consequently, in a resonant state, the push, or voltage, is low at the center where the current is greatest and highest at the ends where the most push is needed to send the current in the opposite direction.

Ohm's Law applies (Fig. 2-2.) In the center, current is high and voltage is low. Therefore, resistance is low. At the ends the opposite condition exists and impedance is high. Theoretically a half-wave antenna should look like a short circuit at the exact center. A short circuit consumes no power. When the antenna is fed at the center, however, the power consumed by the resistance of the conductor and by radiation presents a load that appears to be a workable value of DC resistance. Also. when the antenna is fed at the end, instead of looking like an infinite impedance (open circuit) it again appears to have a real, workable amount of resistance.

Any antenna that is an *odd* number of half wavelengths long has a low impedance in the center, the exact amount depending on the antenna configuration. An antenna that is an *even* number of half wavelengths long has a high impedance in the center. Antennas that are *any* multiple of half wavelengths long have a high impedance at the ends.

An antenna of a quarter wavelength can be fed with respect to a ground under conditions similar to those of a half-wave antenna being fed in the center. In this case, the ground acts as the other half of the antenna, though an infinitely long half. Only the "hot" side is resonant.

### The Half-Wave Dipole

The half-wave dipole is the simplest, most basic of naturally-resonant antennas. It consists of two equal-length conductors supported end-to-end for a total of a half wavelength (Fig. 2-3). The antenna is fed by connecting the source between the two halves. Most of the common antenna configurations are based on this one. The formula to calculate the length is given in Chapter 1.

### The Inverted Vee

Sometimes it is more convenient to support the antenna at the center with the ends sloping downward. This configuration, called an inverted vee, is perhaps second in popularity among amateurs. The angle between the two halves should be no less than 90°, and the most satisfactory results are obtained when the angle is no more than 120°. Angling down the two halves changes the resonant frequency; therefore, a different formula is used to calculate the length. See Chapter 1.

### Multiple Dipoles

Fortunately for amateurs, most of their bands are harmonically related. This makes it possible to use one antenna on several bands. Since an antenna that is a multiple of half wavelengths long has similar impedance

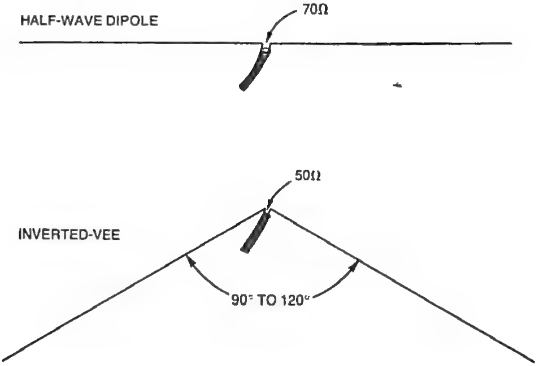



Fig. 2-3. A half-wave dipole and inverted vee antenna. Lowering the ends of the inverted vee presents a lower impedance to match.

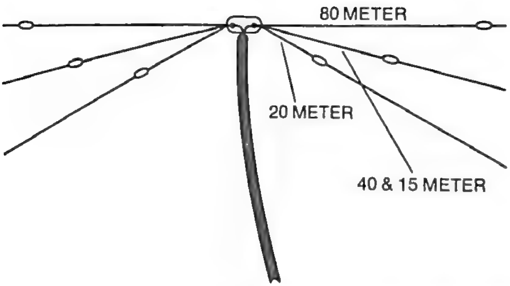



Fig. 2-4. Multiple dipoles fed from a single transmission line. Although there is some interaction, it can be compensated for when tuning.

characteristics to a half-wave antenna when both are fed at the end, amateurs operating on several bands often use an end-fed antenna that is a half wavelength at the lowest frequency. This does lead to some complications in feeding the antenna, which will be discussed later in this chapter.

There is nothing whatever wrong with the idea of connecting several antennas to one feed line (Fig. 2-4). Only the antenna that is resonant at the operating frequency will present a significant load to the transmitter; the others will simply be along for the ride. They will have some effect on one another, however, so pruning may be necessary. See Chapter 5 for pruning procedures.

At the beginning of this chapter, in the discussion of natural resonance, it was mentioned that impulses traveling along an antenna wire would be reflected by a *discontinuity*. Up to now, the discontinuity referred to has been the end of the wire, but it doesn't have to be. A tuned circuit can be inserted at a strategic point in the wire to "end" the wire for one frequency while letting others go by. For example, the overall antenna may be cut for the 80 meter band, and a tuned circuit inserted to terminate the line at the correct point for 40 meter operation. Either a series circuit tuned to 80 meters (Fig. 2-5A) or a parallel circuit tuned to 40 meters will work Fig. 2-5B). For mechanical reasons, parallel traps are the more popular. Again, pruning may be necessary.

**BROADBAND ANTENNAS**

Amateurs frequently try to design their antennas to have a nearly uniform match over a wide portion of the spectrum.

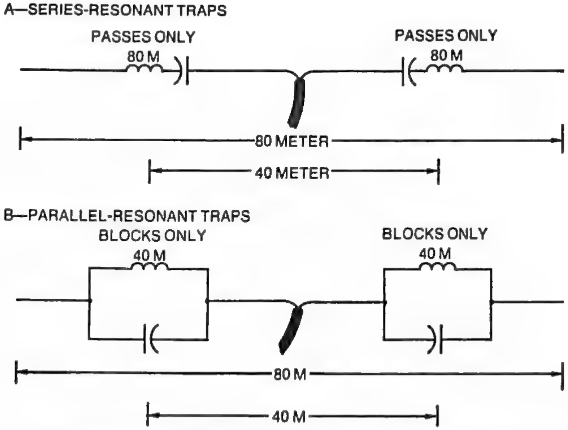



Fig. 2-5. With series traps, the tuned circuits are resonated to pass only the lower frequency (long wire), thus forming a termination to the higher frequency. With parallel traps, the tuned circuits are resonated to block the higher frequency (short wire). Remember, series resonance passes, parallel resonance blocks.

Figure 2-6 shows a Windom antenna, widely used in bygone times. The Windom is a single-wire, half-wave antenna, fed by one-wire feedline tapped in 14% from the center. Today it is most popular as a SWL antenna for receiving, but shouldn't be completely ruled out for transmitting.

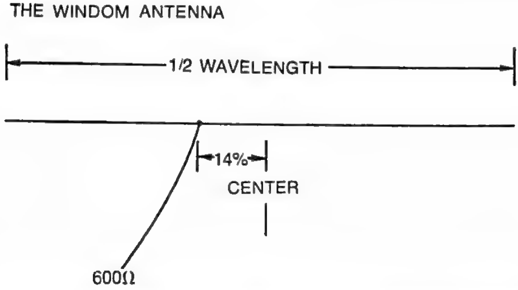



Fig. 2-6. Windom antenna. Very popular for SWL activity; a matching device is needed to use this antenna for transmitting.

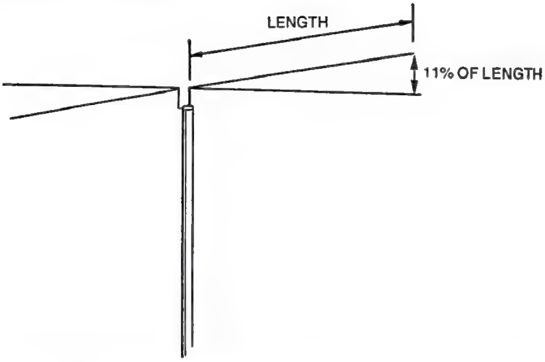



Fig. 2-7. Fan dipole antenna. A very popular broadband antenna derived from the common dipole.

The fan dipole is one very popular broadband antenna, being one of the simplest modifications of the basic dipole. Perhaps the best way of describing it is to say that it has two identical dipoles connected to one feeder, with the ends spread about 11% of their length. The dimensions shown in Fig. 2-7 apply to both halves of the antenna.

A number of designs for antennas made of coaxial cable have been in circulation in recent years. All are different, all are experimental. While wide frequency tolerances are claimed, no general data on coaxial dipoles is available to back up those claims.

One design that seems to have considerable substance is called the "Double Bazooka". This was developed by the staff of MIT for radar use and afterward adapted to amateur use. A half wavelength of coaxial cable is used, with the conductors shorted at both ends. The shield is then opened at the center and the antenna fed between the two halves of the shield. The overall antenna is 2% shorter than a half wave dipole, and one variation uses a coaxial section for only 70% of the overall length, the remainder consisting of single conductor wire.

## RADIATION CHARACTERISTICS

A half-wave dipole radiates most of its signal at right angles to the conductor, with little or no radiation from the

ends. When the antenna is end-fed, the radiation pattern shown in Fig. 2-8 for a half-wave antenna would tend to favor the quadrants toward the feed point, but would remain very nearly at right angles at the conductor.

A full-wave antenna radiates most of its energy at 45° angles to the conductor. Again, if the antenna is end-fed, the lobes closest to the feed point are slightly larger. Each multiple of full wavelengths in an antenna adds additional lobes.

## FEEDING YOUR ANTENNA

The feed line connecting the antenna to the transmitter *must* have impedance characteristics that match the transmitter and the antenna. When the antenna and the transmitter are of different impedances, a transmission line can be selected to have an impedance characteristic and length able to provice a match. Coaxial cable is presently the most popular feedline. In fact, while other kinds of line certainly exist, coax is used in almost all amateur applications.

There are many types of coax available. We will discuss the more common types useful for amateur radio applications. The characteristics of these popular cables are given in Table 1-1.

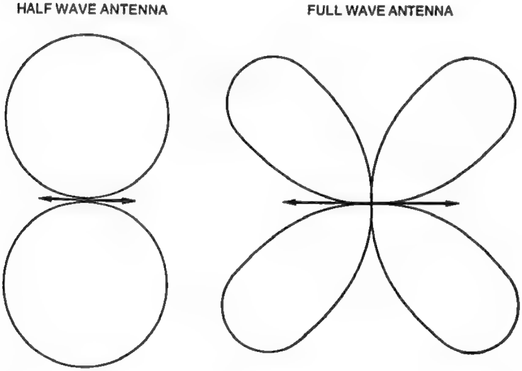



Fig. 2-8. Radiation patterns of half-wave and full-wave antennas.

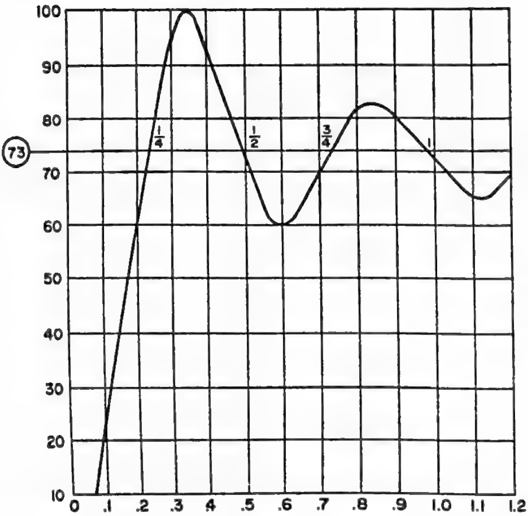



Fig. 2-9. Half-wave dipole impedance vs. height. The characteristic imepdance of an antenna varies with height above ground. This curve for a half-wave dipole, for example, shows an impedance radiation from 100 ohms down to less than 25 ohms at 0.1 wavelength above ground. These two extremes represent a SWR of 1.4:1 and 2.8:1, respectively.

The exact feed-point impedance of an antenna varies with the kind of wire used, the conductivity of the ground underneath, and the height of the antenna above ground. A half-wave dipole, for example, will vary its impedance with height as shown in Fig. 2-9.

From the figure, we notice that the impedance of a half-wave dipole tends to center on 73 ohms. This impedance directly to the output of most amateur transmitters, and should be fed with either RG-59/U or RG-11/U cable. Use RG-59/U for power levels under 500 watts, and RG-11/U higher power.

An inverted vee has a feed-point impedance of about 50 ohms. This is also within the output impedance range of most amateur transmitters and should be fed with either RG-58/U or RG-8/U cable. Use RG-28/U for power levels under 500 watts or so, and RG-8/U cable above that.

Of course, you *can* use the cable recommended for high power with low-power rigs, and it will work perfectly well, but, it is bulkier and harder to handle. Common sense should be the rule.

A Windom antenna presents an impedance in the neighborhood of 600 ohms. This probably won't be within the output-impedance range of your transmitter, thus a coupler or other matching device may be necessary. See Chapter 4 for coupler circuits.

An end-fed antenna can be a unique kind of a beast. It presents a high impedance on all bands to which it is multiple of a half wavelength, but it presents a low impedance to any bands at which it is an odd number of quarter wavelengths. For example, a wire that is one-half wavelength on 80 meters is one wavelength on 40, two wavelengths on 20, and four wavelengths on 10. On all of these bands it presents a very high impedance when fed at the end. That same wire, however, is a quarter wavelength on 160, and 11 quarter-wavelengths on 15 meters. On those bands it presents a low impedance—low enough to be fed directly from the transmitter output, in most cases, or through a simple series-tuned circuit.

End-fed antennas, therefore, are often brought right into the shack with a coupler mounted on the wall at the entry point. Depending on the extent of operation contemplated, the coupler can be a simple L- or Pi-network, or one that can be switched among various other configurations. See Chapter 5 for more information about couplers and antenna matching.

## BUILDING A BASIC ANTENNA

After deciding on the band or bands on which you wish to operate, construction of the antenna must be faced. The particular kind of antenna you build may be up to your discretion, but often the choice depends mainly on the layout of your operating site. If the shack is in the cellar, for instance, you probably would want to avoid an end-fed antenna. Is the site a trifle too small to contain a dipole? How about an inverted vee then? If the shack is on an upper floor with most of the property stretching out beind, an end-fed antenna might be just the thing. It's just a matter of common sense.

### Materials

Theoretically, any wire able to support its own weight can be used for an antenna. Many amateurs, who for various

reasons wish to conceal their antenna, use an extrafine wire. My first antenna was made of doorbell wire; others have used stranded hookup wire. In fact, many antennas are made of any old junk an amateur can lay his hands on. All produce results.

Good practice, however, dictates an eye to the future unless you enjoy climbing a tree or pole in the height of a blizzard to get your station back on the air. In the choice of wire, for example, you might ask, "Will this wire stretch under tension, thereby changing its resonant frequency? How well will it hold up when encrusted with winter's ice? What are the chances of the wire breaking within the insulation?" These are all delightful little surprises pulled off by the aforementioned types of wire. Furthermore, fine wire should be avoided for another reason. The finer the wire, the more sensitive the antenna may be to frequency change.

Antenna wire, then, must be stretch-resistant; it must also be strong enough to hold up under the weight of ice and the whip effect of wind.

In choosing the wire to use for your antenna, there are a few basic rules to remember.

- Insulated wire is better than bare wire.
- Hard-drawn copper is better than soft-drawn.
- Stranded wire is better than solid wire. (Remember, RF current travels only in the outer surface of the wire.)

Generally speaking, the heavier the wire you use, the better. I usually use #12 or #14 AWG, depending on which is available. Soft-drawn copper will stretch some under the strain. Hard-drawn copper, phosphor-bronze, or silicon-bronze won't stretch as much, but they are a bit springy and, therefore, harder to work with. Copper-clad steel can take a lot of punishment without stretching or breaking. However, it is quite springy, therefore a stinker to work with.

Take all these factors into consideration when choosing the wire for your antenna. The softer types of wire can be used for a shorter span, or where there is little strain. Use the tougher types of wire for long spans, or where there may be a great deal of strain. (For example, if one support happens to be a tree.) Problems with springy wire can be minimized if, before installation, you stretch it out, tie off the ends, and leave it for a few days.

Avoid splices if at all possible, but don't be afraid to splice in a few inches when pruning the antenna. When additional length is necessary, use the "Western Union" splice shown in Fig. 2-10. Solder it very thoroughly, and then coat with a good quality, weatherproof, acrylic spray.

### Securing Antennas

With antennas in which the feed point is not supported, care should be taken to keep the strain off the connection between the feedline and the antenna wire. With a glass insulator, the coax can be wrapped first around the insulator, taped, and then connected to the antenna wires.

Many amateurs prefer to use a balun in place of the center insulator. A balun transforms the grounded unbalanced coax to an ungrounded, balanced load. A very popular balun is the one designed by W2AU. It offers a good match over a wide range of frequencies and has some measure of built-in lightning protection. The W2AU balun is only one of several excellent, commercially-made baluns.

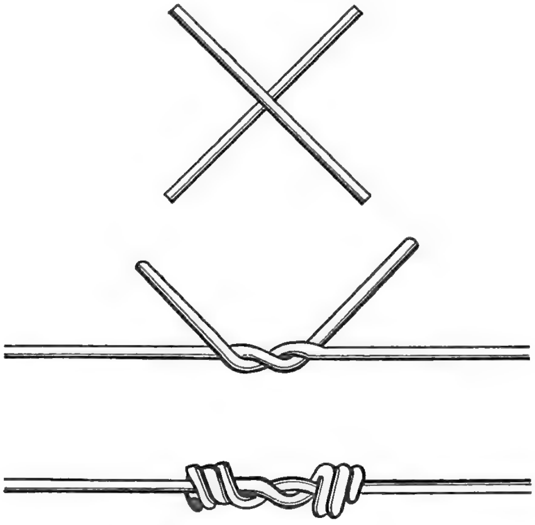


Fig. 2-10. Western-Union splice.

Fasten the ends of the antenna by means of a glass, plastic, or ceramic insulator, then with nylon, fiberglass, or other nonmetallic, weather-resistant rope to a convenient support. Keep the antenna wire as high as possible, and clear of trees, buildings, and other grounded objects (except, of course, for the supports).

To keep the antenna from swinging in the wind, insert a strong spring in the rope connected to one of the supports. Don't draw it up bowstring tight. It is always advisable, especially in climates where ice can accumulate on the wire, to have a certain amount of "give". The tighter the wire is pulled, the more the downward pull in the center will transfer into horizontal pull. Add the weight of a coating of ice, and a tightly-pulled antenna will end up lying on the ground.

After having installed, repaired and taken down many antennas over the years, I've found it advisable, if not almost imperative, to secure one antenna end on a pulley. While you may intend for an antenna to be up for good, that unforeseen catastrophe or that change in plans is bound to occur on a miserable, wet, cold night. At times like that, I prefer not to climb a tree or pole.

Of course, you may have ideas of your own as to how your antenna ought to be secured. As long as it is as high as possible, clear of grounded objects, and insulated from its supports, it's bound to give results.

While we're on the subject, some mention must be made of the ground connection. Although a ground of sorts couples through the AC line, and many amateurs obtain very satisfactory results by connecting to water pipe, many locations will require a separate ground rod or buried ground plane. Remember, one of the requirements of your antenna system is that it must match or be matched to the output impedance of your transmitter or the input impedance of your receiver. The impedance characteristics of any antenna varies not only with its height above ground, as shown in Fig. 2-9, but also with the conductivity of the ground as well. In a location where ground conductivity is poor, you may see a variation of SWR as the weather changes. The antenna will match one way when the ground is wet, another when it is dry, and possibly a third way when the ground is frozen.

If you're satisfied with the results obtained using a water-pipe ground or a single ground rod, well and good. If not,

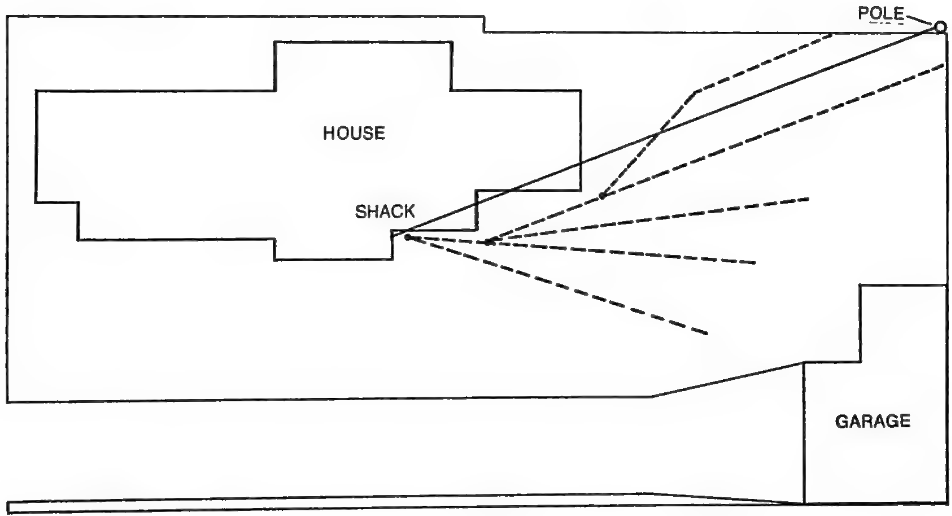



Fig. 2-11. Pattern for laying out ground wires on an odd-shaped lot.

more drastic steps may be in order. Commercial broadcasting stations ensure a constant ground by burying wire radials in the ground, extending a quarter wavelength in all directions from their antenna towers. You may find improved results simply by burying a few square yards of copper screen, or by burying several parallel wires in the ground underneath your antenna (Fig. 2-11). To bury wire, you don't need to dig up the yard. Lay out the wires and then push the them, a few inches at a time, into the ground with the blade of a spade or a sidewalk ice scraper.

Bring a heavy, stranded lead from the ground connection into one large terminal in the shack. Connect ground wires individually from each piece of equipment to the ground terminal. This will be discussed further in the lightning protection chapter.

# Chapter 3
# Transmission Lines

A thorough understanding of transmission lines enables you to match equipment to just about any "antenna"—whether it be the proverbial bedsprings of ham lore or the wire hastily thrown up among the rubble of disaster. Learn the principles well.

## TRANSMISSION LINE BASICS

In most installations, the transmitter and the antenna are considerably removed from one another. It would be nice if we could simply connect the transmitter to the antenna with any piece of wire. Unfortunately, it just doesn't work that way. At radio frequencies, a wire takes on funny characteristics. Let's go back, for a moment, to high-school physics. When current flows through a wire, the wire is surrounded by a magnetic field. If the current varies, the magnetic field moves. And if the magnetic field moves past another wire, it induces a current in that wire.

Now, applying this principle to two wires paired together, which is what a transmission line is, we have the basis to see why the problems exist. Current flowing through wire A in Fig. 3-1 induces a current in wire B which tries to flow in the same direction as A. Now wire B is the return path for the circuit, and has its normal current flowing in the opposite direction to that in wire A. This current produces a magnetic field which

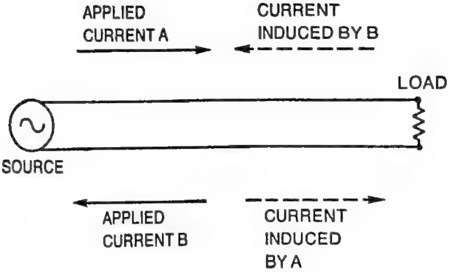



Fig. 3-1. Instantaneous current from the source flows out wire A, and returns on wire B. But each of these two wires generates a current in the other wire, which opposes the current generated by the source.

induces a current in wire A. The induced currents in the two wires oppose the current we are trying to deliver to the antenna, thereby impeding the delivery of power.

In addition, a transmission line consists of two conductors separated by an insulator. This, by definition, is a capacitor. The capacitor allows some minute amount of current to flow, even if the line is open-circuited.

The line, then, acts as if it had a definite amount of impedance. This impedance, which is determined by the inductive and capacitive qualities, is constant, regardless of line length. These features affecting characteristic impedance hold, not only for parallel-conductor line, but for coaxial line as well. Parallel-conductor line having large-diameter conductors spaced close together have a low characteristic impedance; small diameter, widely-spaced conductors have a high characteristic impedance. The exact value of impedance for parallel-conductor lines can be determined by the formula:

$$Z_0 = 276 \log_{10} \frac{b}{a}$$

where b is the center-to-center distance between the conductors, and a is the radius of the conductors. These dimensions can be expressed in metric or English units so long as the same units are used throughout. Coaxial-cable impedance can be calculated by the formula:

$$Z_0 = 138 \log_{10} \frac{b}{a}$$

where b is the inside diameter of the outer conductor, and a is the outside diameter of the inner conductor.

The above-mentioned formulas hold true for air-insulated line. The poly plastic used for insulation in most commercially made lines lowers the characteristic impedance somewhat, but since the end result is known, no harm is done.

While it's theoretically possible to apply the formulas and make any line impedance we desire, certain values are more or less standard to amateur radio work. Although it may seem highly impractical for an amateur to try to make his own line, any number of good reasons, such as availability of commercially-manufactured line with power capabilities high enough to suit the amateur's needs, can necessitate home brewing.

Balanced line is not all that difficult to produce. All that is needed is sufficient wire, a quantity of spacers (which can be quickly cut from polystyrene rod), and a place to stretch the line out. Although the space between wires is important, the interval between spacers is not. Of course there should be enough insulators to keep the wires from changing position relative to one another in the wind. From my experience, the interval between spacers should be about two- or three-times the length of the spacers. Figure 3-2 shows a typical spacing in addition to a detail drawing of the split end of a spacer.

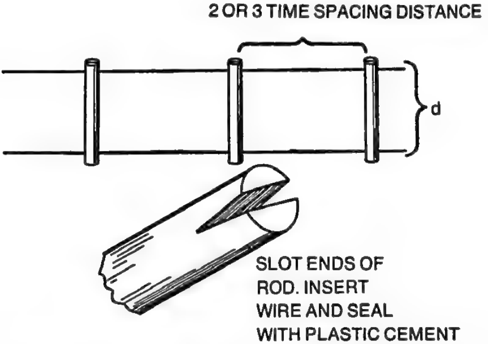



Fig. 3-2. Making open transmission line with wire and poly rod.

Table 3-1. Parallel-Line Dimensions vs. Impedance.

| WIRE SIZE | INCHES CENTER-TO-CENTER | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 15 |
| 22 | 530 | 610 | 660 | 690 | 715 | 740 | 760 | 775 | 785 | 795 | — | — |
| 20 | 500 | 580 | 620 | 670 | 690 | 710 | 730 | 750 | 760 | 770 | 795 | — |
| 18 | 480 | 560 | 600 | 640 | 660 | 685 | 700 | 725 | 740 | 750 | 770 | 795 |
| 16 | 440 | 530 | 560 | 610 | 640 | 660 | 680 | 695 | 705 | 725 | 750 | 760 |
| 14 | 415 | 500 | 540 | 580 | 600 | 630 | 650 | 660 | 675 | 690 | 715 | 730 |
| 12 | 390 | 460 | 515 | 550 | 580 | 600 | 620 | 630 | 650 | 660 | 685 | 705 |
| 10 | 350 | 430 | 490 | 530 | 550 | 575 | 590 | 605 | 625 | 630 | 650 | 675 |
| 8 | 330 | 415 | 460 | 500 | 530 | 550 | 560 | 580 | 600 | 605 | 640 | 650 |
| 1/4" | 220 | 330 | 380 | 415 | 440 | 460 | 480 | 500 | 515 | 530 | 550 | 575 |
| 1/2" | 150 | 250 | 300 | 430 | 360 | 380 | 400 | 415 | 430 | 445 | 470 | 490 |

AWG

Table 3-1 gives a general idea of spacing required for given values of impedance relative to various conductor sizes.

Coaxial line can be much more difficult to make. Unless you're really in a bad way, it's certainly best to buy some well-known, name brand cable. Table 3-2 gives some idea of the conductor sizes used for coaxial ine.

## FEEDING ANTENNAS

It has already been stressed that, for optimum power transfer efficiency, the impedance of the load must match that of the source. To the antenna, the source is the transmission

Table 3-2. Coaxial Cable Dimensions vs. Impedance.

| INNER COND | INSIDE DIAMETER OR OUTER CONDUCTOR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | .15 | .2 | .3 | .4 | .5 | .6 | .7 | .8 | .9 | 1.0 |
| 18 | 80 | 97 | 120 | 139 | 150 | | | | | |
| 16 | 65 | 82 | 107 | 124 | 138 | 148 | | | | |
| 14 | 50 | 69 | 93 | 110 | 123 | 135 | 142 | 150 | | |
| 12 | | 55 | 79 | 95 | 110 | 120 | 130 | 139 | 142 | 150 |
| 10 | | 45 | 65 | 82 | 95 | 105 | 115 | 124 | 130 | 135 |

AWG

line. For efficient power transfer, the impedance of the antenna must equal the characteristic impedance of the line. If the line and the load do not match, and the load fails to accept the power made available to it, the power that is not accepted by the load must go somewhere else. The line itself, not being a true source, can either radiate the power, or deliver it back to the transmitter. Both situations are undesirable.

Antennas can be either voltage-fed or current-fed. Since the voltage and current of an antenna are out of phase with one another, maximum current existing at the point where the voltage is minimum. (See Fig. 3-3.) The particular point where power is introduced into the antenna determines whether it is voltage fed or current fed. Voltage loops (maximums) exist at the ends of a full-wave antenna, or at half-wave intervals along the antenna; current loops exist at odd multiples of quarter-wavelengths from the end, or at the ground end of a quarter-wave vertical antenna. An antenna has a high impedance at voltage loops and a low impedance at current loops.

Coaxial line is presently the most popular for current feeding at points where the impedance is less than 100 ohms, while parallel line is preferred for higher impedance feeding.

### Baluns

Most antennas today are current-fed using coaxial line. However, when the antenna is balanced, as is the case of a

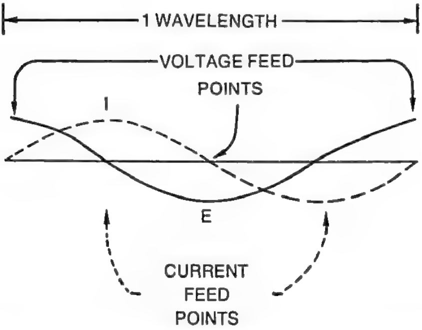



Fig. 3-3. Voltage and current loops on one wavelength of a long wire antenna.

common dipole, and is fed with coaxial line, the unbalanced line can cause some undesirable effects. It is often felt desirable to convert the unbalanced condition of the coaxial line to a balance cicuit for connection to the antenna. There are several ways to accomplish this. Collectively, the devices used are called *baluns* (BALanced to UNbalanced).

Baluns differ somewhat in principles of operation. Some types, in simplified form, turn out to be broadband transformers having an unbalanced primary and a balanced secondary. These are usually wound on toroid cores, and are quite compact. Their operation principles are self-explanatory. Typical balun configurations are shown in Fig. 3-4. Other balun circuits use a half wavelength of coax to feed the legof the antenna that would otherwise be grounded. These step the impedance up four-to-one, and are often used in VHF work, where a half wavelength of coax has a practical size. The coax section, being a half wavelength long delivers power to its load 180° out of phase from its source, which is the other leg of the antenna. Thus the two halves of the antenna are fed 180° out of phase with one another but neither half is grounded. This satisfies the description of a balanced circuit. The balancing section of coax is doubled back on itself so that it doesn't radiate.

Some of the problems of feeding a balanced circuit with an unbalanced line stem from undesired currents flowing in the outer surface of the outer conductor of the coax. These currents can be eliminated quite simply by shorting them out. The trick is to short them out without shorting out the antenna. If a piece of line one-quarter-wavelength long is brought from the hot lead back to a point on the coax a quarter wavelength from the antenna feed point, the undesired currents can be shorted out at that point. The antenna feed point is a quarter wavelength away from the short. A shorted section of line has a very high impedance a quarter wavelength away from the short. Thus it has virtually no effect on the operation of the antenna. The undesired currents in the outer conductor of the coax are nonetheless shorted out, satisfying the requirements of feeding a balanced circuit.

### The Quarter-Wave Stub

When it is necessary to match a line of one impedance to a load of another, we can take advantage of the distribution of

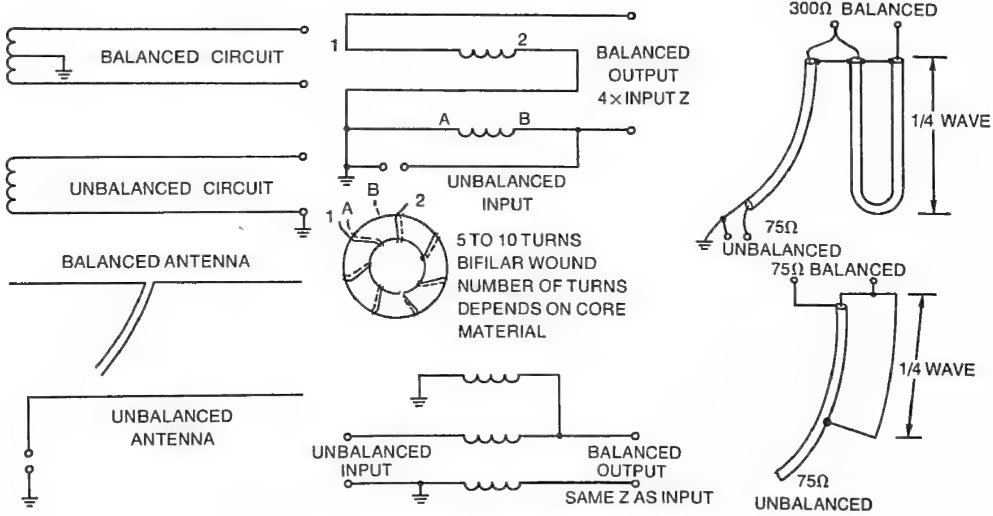



Fig. 3-4. Typical balun circuits; difference between balanced and unbalanced circuit.

voltage and current in a quarter-wave section of transmission line. Since there is a voltage loop at the open end, and current at that end is minimum, by definition it is a very high impedance. The other end is a short circuit. Thus the impedance along the line varies anywhere from near infinity to a short circuit. By tapping the feedline into the proper place along a shorted section of line, we can match it to any feedline impedance value. Also, by adjusting the length of the stub, we can match it to any load impedance. The quarter-wave stub can then be combined with the balun previously described to offer both a balun and impedance-matching circuit.

When matching a high-impedance line to a low-impedance load, we can use an open section of line a quarter wavelength long. In using either an open or a shorted section of line, the position of the feed point must be determined experimentally, by adjusting for minimum SWR. Figure 3-5 shows these two arrangements.

### The Series Quarter-Wave Line

We can also match a line to a load by inserting a quarter-wave section of line in series. The impedance of the matching section is determined by the impedance of the line and that of the load to be matched, using the formula:

$$Z_0 = \sqrt{Z_r Z_s}$$

where $Z_0$ is the impedance of the matching section, $Z_r$ is the impedance of the load, and $Z_s$ the impedance of the feedline. This scheme, illustrated in Fig. 3-6, works quite well over a range of about 50- to 600-ohms, matching-section impedance.

## MATCHING EQUIPMENT TO FEEDLINES

Once we have the transmission line matched to the load, the next step is to match the transmitter to the line. This is generally done with an antenna coupler or tuner. At this end of the line, it becomes practical to take advantage of the added selectivity provided by another tuned circuit.

In an antenna coupler, whether it is called a tuner, a transmatch, or whatever, the principles are generally the same. The low impedance, unbalanced transmitter output is transformed to the higher impedance, sometimes balanced feedline by utilizing the impedance gradient in either the inductive or the capacitive elements of a tuned circuit.

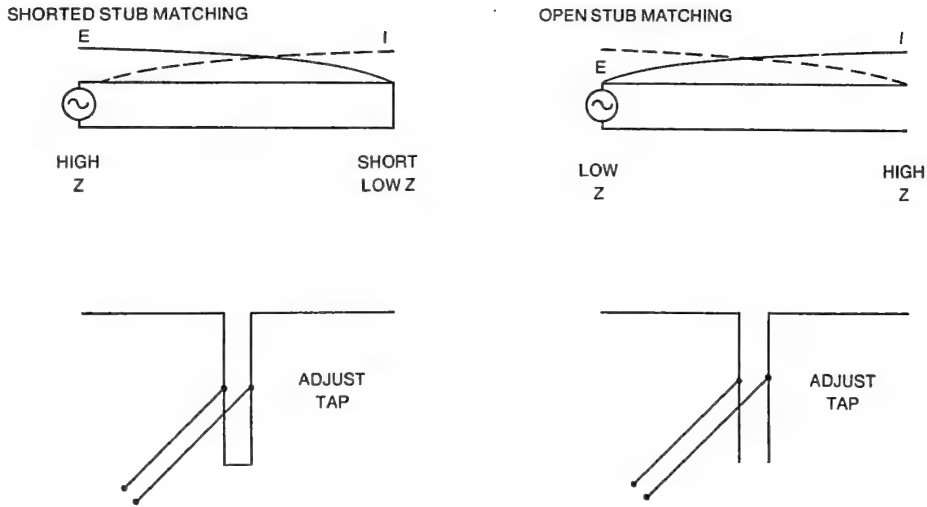



Fig. 3-5. Open and shorted quarter-wave stubs.

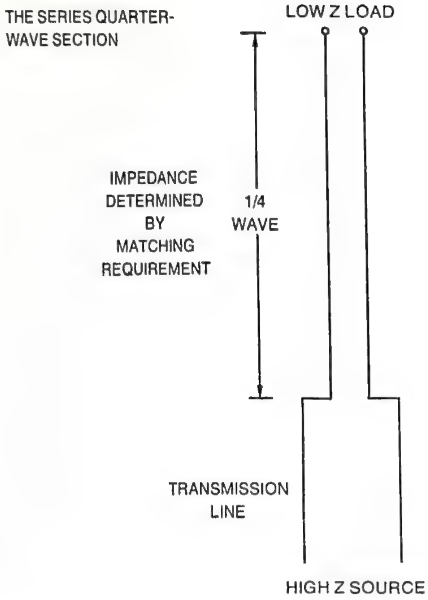



Fig. 3-6. Matching impedance with a series, quarter-wave section.

Sometimes this is combined with the transforming action of a coupling link. The variation of coupler circuits is as wide as one's imagination, and often depends on what parts are available.

Many amateurs that use antenna couplers devise some switching arrangement to adapt the circuit for multiband use. A coupler can be complex enough or simple enough to suit your own needs. Some common arrangements are shown in Fig. 3-7. Many amateurs operate very successfully with neither coupler nor balun. It's all up to one's individual preference.

The initial adjustment of a coupler can be a stinker, especially if the operator is inexperienced. The instructions given in Chapter 4 for tuning up a simple pi network can easily be adapted to virtually any kind of coupler and, with a little practice, very satisfactory results obtained.

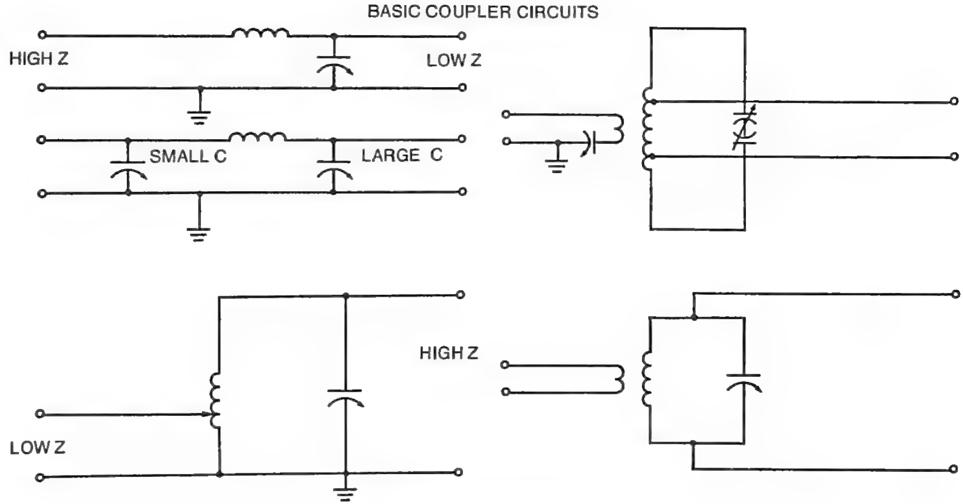



Fig. 3-7. Basic coupler circuits.

# Chapter 4

# Couplers, Traps, and Filters

The antenna coupler, also called a tuner, enables the antenna to take power from the transmitter. It is essential when feeding a transmitting antenna that the antenna impedance match the output impedance of the transmitter. If this condition does not exist, results will be very disappointing (or disastrous) unless some device can be inserted between the transmitter and the antenna to make the source and load match. This is the function of the coupler.

Now, many antennas do not need a coupler. Dipoles, inverted vees, ground planes, and other antennas having a low-impedance feed point can be connected directly to the transmitter output with excellent results. Other types need a coupler.

There are as many coupler circuits as there are people with imagination. Some are made to go from a balanced source to an unbalanced load; some are the other way around. But the coupler that fits the widest variety of today's amateur needs matches a low-impedance, unbalanced source to a high impedance, unbalanced load. Most end-fed antennas offer such a load.

## EVOLUTION OF COUPLING CIRCUITS

In the days when radio was young and anything above ten meters or so was science fiction, antennas were often coupled

through a capacitor directly to the plate of the final amplifier tube (Fig. 4-1).

While this matched impedance (the plate circuit of a tube is a very high impedance), it also fed all the harmonic garbage in the plate to the antenna. Also, stations using this scheme often had RF voltage showing up in the most unwelcome places. Consequently, the FCC recommends against using this scheme. The two aforementioned problems are avoided by taking the power from the tuned plate circuit and transmitting it to the antenna through a low-impedance path. Just before and after World War II, most transmitters coupled their outputs by way of a few turns around the plate tank coil (Fig. 4-2A). A low-impedance line was then coupled through another tuned circuit to the antenna.

Some operaators eliminated the link at the antenna tuner by tapping into the tuned-circuit inductance (Fig. 4-2B). Variations of this scheme are still in use in some commercial installations.

The next logical step seems to be putting the low-impedance, transmitter output in series with the tuned-circuit elements. This scheme evolved into the L-network (Fig. 4-2C).

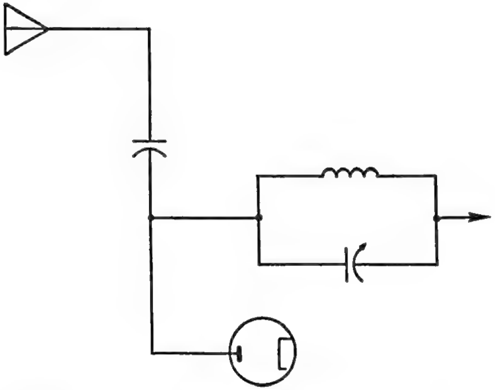


Fig. 4-1. An early method of feeding an end-fed antenna. While this method did indeed match the high impedance of the antenna, it also transmitted all the harmonic garbage present in the plate of a class-C amplifier. Consequently, this method is not recommended.

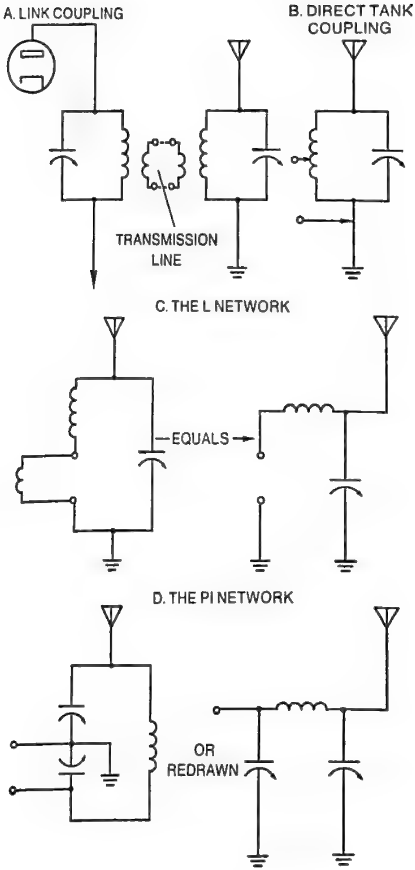



Fig. 4-2. Evolution of modern output coupling. At A, several turns coupled into the tank circuit, then a low-impedance transmission line carried it to another tuned circuit for matching to the antenna. At B, the coupling loop was replaced by direct coupling into the tank inductor. At C, the low-impedance portion of the tank inductor became part of the antenna matching inductance, thus an L network. At D, the capacitance is split to form the pi network.

The L-network works very well. However, there are those who would go one step further and want full control over the impedance transformation ratio. This can be accomplished by splitting the capacitance into two elements and making them variable. Then, by moving the grounded point from the junction of the inductance and capacitance, we find that we have arrived at the most popular impedance matching circuit in use today, the pi network (Fig. 4-2D).

The popularity of the pi network can easily be shown by pointing out that practically all commercially-built transmitters now use it in some form for their output circuits. It works just as well at the antenna end, transforming the low characteristic-impedance of the coax to the high-impedance antenna feed point with a near-undetectable standing wave ratio. Figures 4-2 and 4-3 show commercial versions of couplers using the pi network.

**A QUICKIE L-NETWORK**

This coupler was first written up for *73 Magazine* and appeared in the Nov./Dec. 1975 issue. It is used here with permission. When the cost of a suitable metal enclosure becomes a burden, or when you find there is no nearby source, you have to be resourceful. An kid's old school lunchbox will house a coupler for field and emergency use.

The part values shown work well with a 123 foot antenna. It is very possible that different environmental conditions, such as ground conductivity, will require you to fudge the coil a bit for optimum performance, but the values given should work quite well.

Before mounting any parts, strip the paint from around all mounting holes and from around the portion of the case and cover where the two make contact with one another. This ensures good grounding between them. Interconnect all components with wire rather than using the case ground as a signal path. Mount the coil on insulated standoffs, keeping it equally spaced from the top, bottom, and sides. Figures 4-4 and 4-5 show the schematic diagram and photograph of the tuner. For a complete picture of the Quickie L-Network see Fig. 4-6.

Connect the antenna to the coupler, then the coupler to your receiver. Adjust C1 for maximum receive sensitivity. Next connect the transmitter, keyed with reduced drive, and

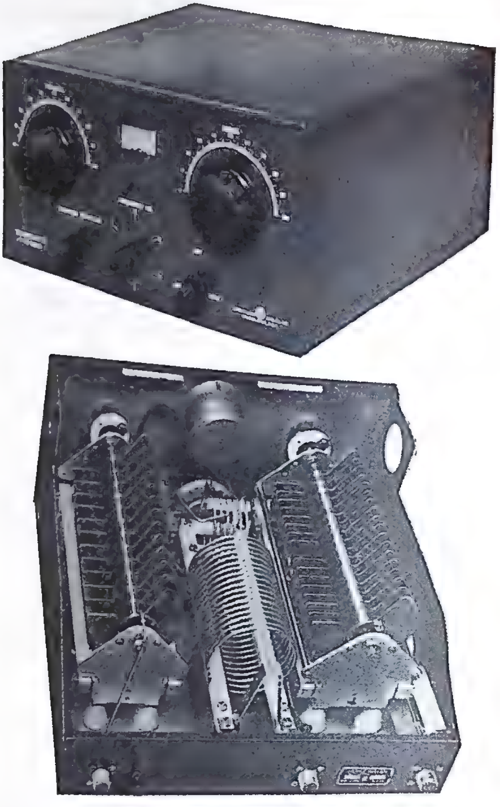


Fig. 4-3. Internal and external views of a Transmatch, a commercially made antenna coupler. Photos courtesy James Millen Company.

fine-tune for minimum SWR. See Chapter 5 for detailed tuning instructions.

### PI IN THE BREAD BOX

A pi network is the most effective, economical matching device an amateur can build. Suitable metal enclosures are

Fig. 4-4. The Transmatch Jr., a low-power version of the Millen Transmatch. While the latter can handle the legal limit, its less expensive brother, shown here, is good up to 300 watts. Photo courtesy James Millen Company.

expensive and often hard to obtain at any price, hence the idea or constructing the matching circuit shown in Fig. 4-7 in a bread box. Even if you can't find one dirt cheap in the Salvation Army store, the price of a new box is far below that of a professional enclosure, and a bread box will add a splash of color to your shack. Those feeling degraded by the use of such an enclosure can find some comfort by painting it olive drab.

The author was fortunate enough to find a rotary inductor at a ham auction. Such a device is very expensive when new.

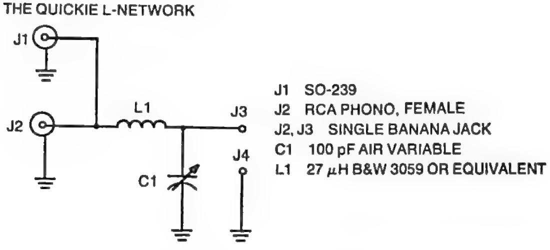



Fig. 4-5. The Quickie L-Network, a simple but effective coupling circuit, works well into a 123 foot antenna.

Fig. 4-6. The Quickie L-Network is shown here constructed in an old school lunchbox, but any suitable metal enclosure can be used.

However, B&W makes a line of air-core inductors that adapt very nicely to this application. For capacitors, I was fortunate enough to find an E.F. Johnson #154-30, which has a maximum capacitance of 1000 pF. If you cannot get one of these gems, a two-section broadcast tuning capacitor should be sufficient. For the high-impedance end (C2), you're dealing with higher voltages, and the wider-spaced the capacitor plates, the better. E.F. Johnson's #154-0009 will do the job nicely, or if you have

an old ARC-5 you feel like cannibalizing, they contain several excellent capacitors of sufficient capacitance.

The coil, a B&W #3029 has sufficient inductance to provide a series tuned circuit which will load a half-wave, 80-meter antenna on 160 meters. For 80- through 10-meters, you have a choice of either a pi or an L-network. To select either or these configurations or to select a band, insert the shorted double banana-plugs into the proper jacks according to the tabulation with Fig. 4-7. This arrangement provides better isolation of unused sections of the circuit.

When mounting the input connector and the ground terminal to the box, strip the paint off both inside and outside where the terminal and connector come in contact with the box. This provides a good ground connection to the box. Nonetheless, run separate wires to all ground connections within the box, rather than using the box itself as part of the signal path. Wiring within the box is done with #16 or larger single conductor wire. (Stranded wire would be better, but single conductor is easier to get.)

Note that the rotor plates of C2 are isolated from ground, thus allowing it to be used in the series-tuned-circuit configuration on 160 meters. This feature can be eliminated if no 160 meter operation is contemplated. It is handy, however since it allows better match to quarter-wave antennas on the other bands. Likewise, if you don't really want a pi network, C3 can be eliminated just for the L of it.

For the output, you can use a high-voltage ceramic insulator, or you can mount the coupler right over the antenna entrance. Personally, I prefer the latter.

For full versatility, you will need four double banana-plugs shorted with the same size wire used in the tuner's internal wiring. To set the unit up as a pi network, insert plugs into J2, J9, and J11. Select the desired band by inserting a plug into J3 thru J8, as desired.

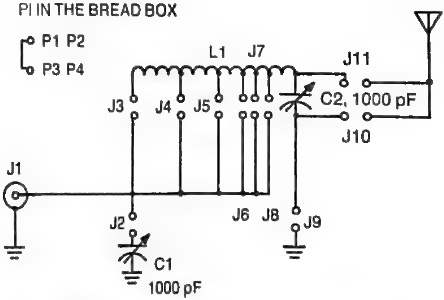
To use the tuner as an L-network, remove the plug from J2.

To use the tuner as a series tuned circuit, remove the plugs from J2, J9, J11. Insert a plug into J10.

To leave the system grounded for lightning protection during non-operative periods, Insert plugs into J9 and J10.

For tune-up procedures, refer to Chapter 5.

Positioning of taps may have to be varied due to individual location conditions. It may be necessary to experiment or to check resonance with a dip wavemeter.




| BAND SELECT | CONFIGURATION SELECTION |
|---|---|
| J3-160 | PI NETWORK-J2, J3, AND J9 |
| J4-80 | L NETWORK-J3 AND J9 |
| J5-40 | SERIES TUNED-J10 |
| J6-20 | LIGHTNING GND-J9 AND J10 |
| J7-15 | |
| J8-10 | |

J1 SO-239 CONECTOR
J2 THRU J11 DOUBLE BANANA JACKS
C1 1000 pF E.F. Johnson x154-30 or TWO AM BROADCAST VARIABLE CAPACITORS GANGED TOGETHER
C2 200 pF. E.F. Johnson 154-0009
P1 THRU P4 DOUBLE BANANA PLUG SHORTED
L B & W 3029, TAPPED AS FOLLOWS:
160 ENTIRE COIL
80 ABOUT 50%
40 ABOUT 25%
20 ABOUT 15%
15 ABOUT 10%
10 ABOUT 4 1/2 TURNS.

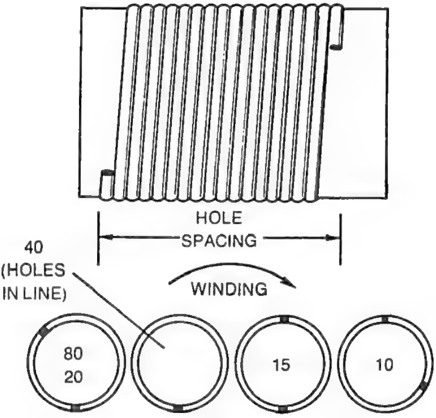
Fig. 4-7. Pi in the Breadbox. This pi-network circuit provides the ultimate in control of matching. Selection of bands and circuit configurations is performed by double banana - plugs.

## CHEAPSKATE TRAPS

Commercially-built antenna traps cost from $12 to $25 a pair, depending on the manufacturer. If you are willing to put forth a little elbow grease, however, you can make a pair just as effective as the best commercial brands for 10% to 20% of their cost.

The coils are wound on a three-inch length of 1 1/2-inch plastic pipe using #14 enameled wire (Figs. 4-8 and 4-9). The capacitors, 33 pF NPO type with a 1000-volt rating, cost about 15 cents each; Slippery Sam, your local surplus man, might have them for less than a dime. A pair of common drain plugs seal the ends of the form, and a few feet of plastic electrical tape complete the job. For a final touch, spray inside and outside with clear acrylic plastic to keep out moisture.

A trial pair of 40-meter traps came out matched to within 1% of each other, and needed no adjusting. Lab tests indicated




HOLE POSITIONS

| BAND | HOLE-SPACING | TURNS | CAPACITOR |
|---|---|---|---|
| 80 | 1 5/8 INCH | 24 3/8 | 82 pF |
| 40 | 1 3/32 INCH | 19 | 33 pF |
| 20 | 5/8 INCH | 9 3/8 | 22 pF |
| 15 | 1/2 INCH | 7 1/2 | 15 pF |
| 10 | 1 1/16 INCH | 10 5/16 | 5 pF |

Fig. 4-8. In the end view, the hole nearest you is at the bottom of the form, and is the start of the winding. If the coils are wound precisely as shown, little or no trimming is necessary. Coil data is calculated for winding on 1 1/2 inch plastic pipe which has an outside diameter of 1 7/8 inches. The hole spacing shows the distance along the form, or length of winding. With coils having a fractional number of turns, position the end hole proportionally along the form from the beginning hole.

Fig. 4-9. In spite of its cheap construction, the completed trap doesn't look all that bad. The capacitor is inside the coil. This particular one didn't need the "gimmick" trimmer.

a Q of about 24, giving them a bandwidth of 300 kHz—just right to span the 40-meter band with their center frequency of 7125 kHz.

Before winding the coils, secure one end of the wire in a vise and pull the other end until the wire begins to stretch. This removes the bends, ensuring a neat-looking coil. Drill two holes in the pipe with a #50 drill, spaced according to the information given in Fig. 4-8. Leaving the far end of the wire secured in the vice, insert about three inches of the other end through one of the holes from the outside and bend it over to secure it. Then, keeping the wire somewhat tightly drawn, turn the form to wind on the required number of turns. This procedure will give you a neat, professional-looking coil. When the winding is complete, pass the remaining wire through the second hole, being careful not to let the coil spring loose, and bend it over.

Inside the coil form, at the point where the ends pass through, scrape off the enamel all around the wire for about 1/4 inch. Solder the capacitor leads to the coil, keeping the

leads straight. Then spray the interior of the form with clear acrylic. Cement the plugs in place with epoxy or any good, waterproof service cement, leaving enough wire protruding through to make your connections. Cover the outside with plastic tape and spray with clear acrylic.

Check the resonance of your traps with a dip wavemeter. Unless you've made a mistake or the capacitors are way off tolerance, the traps should be pretty close to resonating in the center of the band. Make slight adjustments by spreading the turns of the coil to increase the resonant frequency, or by adding a "gimmick" capacitor on the outside of the coil.

A gimmick capacitor is two pieces of insulated wire, twisted together and soldered to the coil. Capacity can be adjusted by varying the amount twisted together. Once the gimmick is adjusted, tape the outside of the whole works and spray again with clear acrylic.

**TVI FILTERS**

Television interferance has been a major bugaboo to amateurs since that medium blossomed after World War II. To cover the many causes and remedies would depart considerably from this book. However, the most common causes and their remedies involve antenna systems and are corrected either with a low-pass filter in the transmitting system or with a high-pass filter on the TV receiver.

It is of cardinal importance for the amateur, whether he presently has a TVI problem or not, to know just where his responsibilities end and his neighbor's begin. Legally speaking, if the trouble is caused by excessive harmonic or spurious signals coming from the transmitter, the amateur must clean it up; if the trouble results from the TV receiver responding to signals other than those on the TV channel's frequency, it is the TV owner's responsibility. Most times, the neighbor will not be as well informed about the technical aspects of the problem as the amateur. So long as the neighbor's attitude is reasonable, though, the amateur should *advise* him what to do and how to do it. On the other hand, if the amateur's transmitter is free of harmonics and spurious radiation, and the neighbor refuses to cooperate, the amateur has no further responsibility. Though television is a public medium it does not have priority over a properly-tuned and filtered amateur station.

Although it is a very hard fact for a man to swallow after he has paid many hundreds of dollars for a TV set, often as not, the problem lies in the TV receiver. Consider these facts. A television signal has to be 100 times as strong for satisfactory reception as does an AM broadcast signal. Sets more than 40 miles or so from the TV transmitter are considered by the FCC to be in a "fringe area". A single TV channel is 1000 times as wide in the communications spectrum as an AM broadcast station, and takes up six times as much spectrum space as the entire AM broadcast band. Consequently, the front end of any TV set is as broad as a barn door. Moreover, any TV set tuned to channel 2(54 to 60 MHz) has the 6-meter amateur band (50 to 54 MHz) virtually within its passband. TV sets tune so broadly that the FCC will not assign immediately adjacent channels in a given community, nor will cable companies put stations on immediately adjacent channels. Generally speaking, sets built before 1964 are the worst offenders, expecially since some of them have a 21 MHz IF, which just happens to fall at the 15 meter amateur band.

Bad as some TV sets are, you still have to be sure your transmitter is clean. A good grounding system and a well-matched antenna are essential. Put a low-pass filter into your transmitting system and a high-pass filter on your own TV. Once you can transmit without interfering with your own TV, the fight is more than half over; the FCC will then likely be on your side.

There are several good makes of low-pass filters for amateur use and, while most or all of them may be effective, the FCC has, on two occasions, specifically recommended the Drake TV-3300-LP. This model is fairly expensive, but is should never wear out and it's beauty. Several filters are shown in Fig. 4-8.

When you learn of a case of TVI you should, if at all possible, arrange to see it for yourself while a fellow amateur operates your transmitter. Don't try to "snow" your neighbor with a lot of meaningless technical talk. He may not be electronically inclined, but he wasn't born yesterday either. Explain the situation to him, assuming he will listen, and advise him how and where to get a high-pass filter. (Here we assume you have already cleaned up your own rig.)

If the TV set is fairly new (less than ten years old) and if the neighbor is the original owner, advise him to write to the

manufacturer, giving the model and serial numbers of the set. The manufacturer is required to make a filter available. The better-known manufacturers will supply a filter free of charge; others charge a nominal amount. It is the neighbor's responsibility to get it installed. *Don't ever* touch a tool to someone else's TV. When he has trouble a year or so later, you may hear him say, "Well, it worked all right until you fooled with it." You are not obligated to install a filter or to pay for such work in someone else's equipment.

If the TV set is an older model, or if it is second hand, the owner will have to buy his own filter. Here again, the author recommends Drake as an excellent brand. For mild cases—that is, cases in which you still can see the picture through the pattern—the $2 filter available from an electronic hobby shop will work.

If you're coming in on a TV connected to a cable system, verify that your own, properly-filtered TV is free of interference when connected to a good antenna. If you find it free of interference, you have a strong case that your transmitter is not at fault, for any defect in your transmitter that would interfere with a TV receiver will most likely affect them *all*. If you can filter it out of your own TV, then it's your neighbor's responsibility to filter his.

I personally prefer and recommend the Drake line of TVI filters for the transmitter or TV receiver (Fig. 4-10). While it is quite possible to home-brew a filter, considerable skill is required if it is to work right. The coils are small and must be precisely wound. Moreover some amount of mechnical skill is needed to properly fabricate a box having partitions between each two filter section.

For those who feel they have this skill, Fig. 4-11 shows a basic low-pass filter. The cutoff frequency is 40 MHz, and parts values are given for both 50- and 75-ohms. For the capacitors, use close tolerance dipped mica. Where two values are in parallel, twist the leads together so that no lead length exists between the two capacitors.

Build the filter in a 2 1/4 × 2 1/4 × 4-inch minibox, such as the Bud Cu-3003A or Cu-2103A, or approximate equivalent. Isolate the filter sections with partitions cut and bent from #18 gauge (0.040-inch) aluminum, or similar stock. Ideally there should be three partitions, one each in the middle of L2, L3,

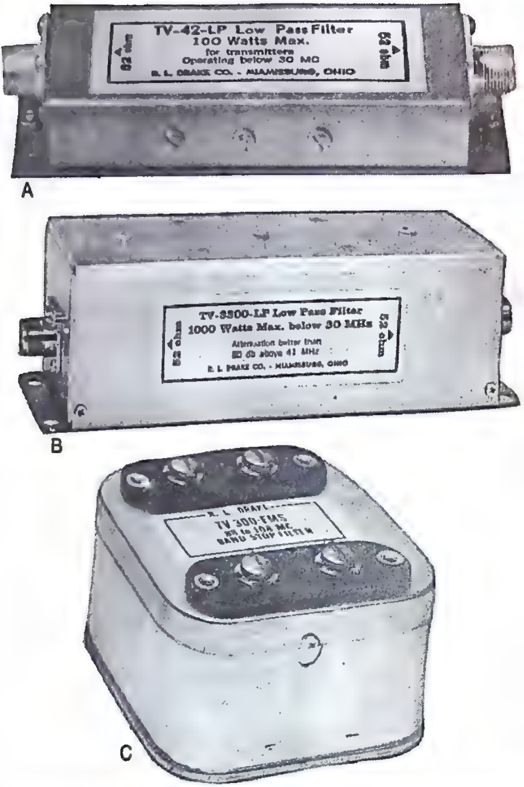



Fig. 4-10. Several commercial filters suitable for eliminating TVI. Spurious radiation from the transmitter can be attenuated with either the low power Drake TV-42-LP filter (A) or the high power TV-3300-LP filter (B). At the TV itself, insertion of a high-pass filter (C) prevents signals below the TV bands from entering the channel-select tuner. Photos Courtery R.L. Drake Company.

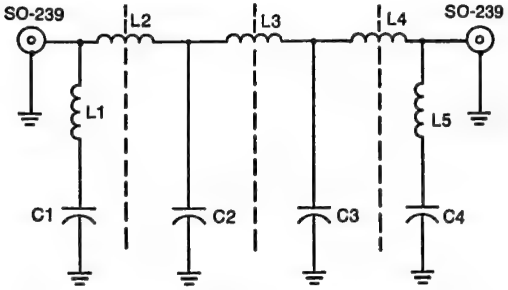
and L4. It is more practical, however, to use two partitions isolating the coils from one another.

Mount the coils on insulated stand-off terminals such as the E.F. Johnson Rib-Loc variety, keeping all leads as short as

possible. For the input and output connectors, use a type SO-239. The filters are symmetrical; either end can be input or output.

The coils can either be hand-wound or they can be cut from a B&W Miniductor, Type 3002. The *exact* number of turns for each value of inductance appear in the figure.

Hand-wound coils are made with #12 enameled wire. Close-wind the coils around a 7/16 inch rod. Dope the coils and slip them off the rod after the dope is dry (Fig. 4-12).




| Part | 50 ohm | 75 ohm |
|---|---|---|
| L1 | .21 uH | .3 uH |
| L2 | .32 uH | .46 uH |
| L3 | .4 uH | .51 uH |
| L4 | .32 uH | .46 uH |
| L5 | .21 uH | .3 uH |
| C1 | 47 pF | 120 pF parallel with 39 pF |
| C2 & C3 | 33 pF | 110 pF |
| C4 | 47 pF | 120 pF parallel with 39 pF |

| INDUCTANCE ($\mu$H) | B&W 3002 | Hand Wound |
|---|---|---|
| .21 | 3 1/2 | 3 2/3 |
| .3 | 5 | 5 |
| .32 | 5 1/3 | 5 1/3 |
| .4 | 6 2/3 | 6 1/2 |
| .46 | 7 2/3 | 7 4/10 |
| .51 | 8 1/2 | 8 1/4 |

Fig. 4-11. Ideally, the three sections should be divided by grounded partitions through L2, L3, and L4. It is more practical, however, to have one partition between C2 and L3, and another between C3 and L4.

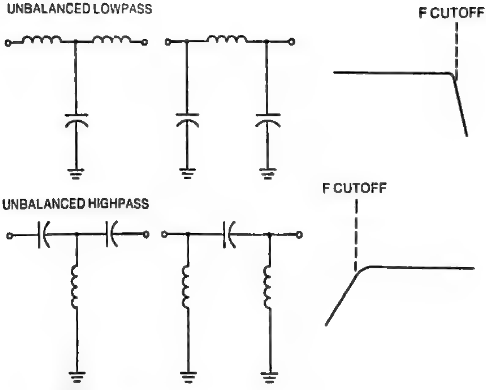



Fig. 4-12. Some examples of simple circuits for unbalanced lowpass and unbalanced highpass filters. Calculation of the values for these filters must take into account not only the cutoff frequency but also the impedances they work into at each end. In amateur radio work, the impedance in and out of these filters will usually be the same, either 52-, 75-, or 300-ohms.

On a TV receiver, a high-pass filter usually will cure ıterference problems. Electrically, a high-pass filter is the exact inverse of a low-pass filter. That is, where capacitors are used in one, inductors are used in the other, and vice-versa. Because TV antenna inputs usually are balanced circuits, these simple filters must be modified to the balanced configuration shown in Fig. 4-13.

Mass production makes high-pass filters for TV antennas readily available. Cheap models for twinlead are on the shelf in almost every store selling antenna equipment, and stores that offer MATV equipment offer high-pass filters for 75-ohm coax. Availability is such that it really is impractical to home-brew one.

Drake makes top-of-the-line filters good for severe problems, or electronic store cheapies work quite well for moderate interference. If you have a severe problem and can't get a high-quality model, several "cheapies" can be cascaded. Their performance can be enhanced further if they are mounted inside a Minibox and shielded from one another.

For best suppression, mount the filter inside the TV cabinet right where the twinlead enters the tuner. If the filter is provided with a ground strap, make sure the strap is well grounded to the chassis.

Occasionally an amateur or SWL may find himself living close to a high-power station operating in another service. Such stations can often brute-force their way into even a well-designed receiver and be a real interference problem. This can be solved with either a series- or a parallel-tuned wavetrap, or by a combination of the two. Refer to Fig. 4-14 for the circuits.

These wavetraps are best made with slug-tuned coils and fixed silver-mica or dipped-mica capacitors. If the interfering

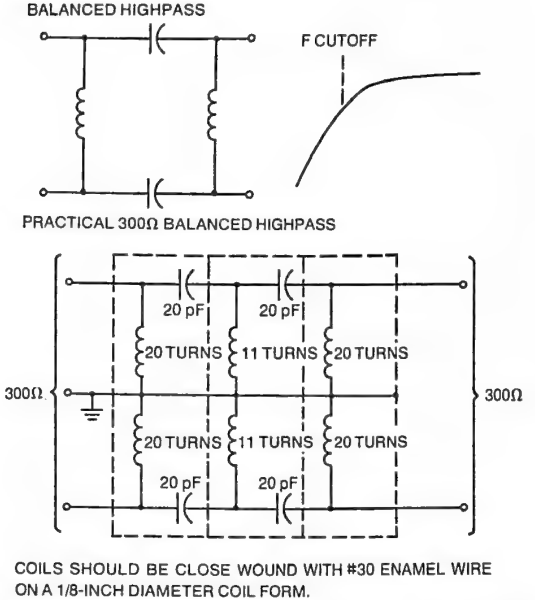
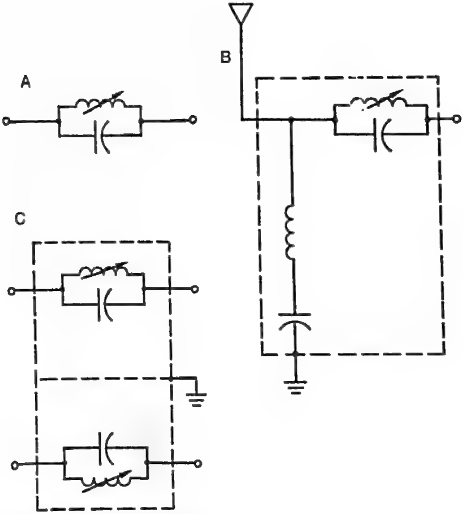



Fig. 4-13. A simple, balanced high-pass filter and a more effective version suitable for use on a TV set. Each stage should be housed in a separate compartment and short, direct connections used throughout.




EXAMPLE: MILLER 4201-A
AND 15 pF TO BLOCK 6 METERS

Fig. 4-14. When studying these traps, keep in mind that a parallel-resonant circuit blocks the tuned frequency, and that a series-resonant circuit passes the tuned frequency. Circuit A, then, will block whatever frequency it is tuned to, but pass all others. The parallel-resonant stage of circuit B will block the tuned frequency, and the series-resonant stage will shunt it to ground, thus providing a much greater attenuation than circuit A. For a balanced line, use circuit C. It provides two parallel-resonant stages so that each line attenuates the undesired frequency.

station is in the AM broadcast band, the ferrite "loopsticks" used in many AM radios, together with a fixed capacitor of 300 pF for the low end or 75 pF for the high end will work quite well. For other frequencies, calculate the values of L and C from the formulas in Chapter 1 to tune the trap to the frequency of an interfering station. The J.W. Miller division of Bell Industries makes an excellent line of slug-tuned coils designed to cover nearly any part of the spectrum below VHF. Part numbers and inductance ranges are given in Table 4-1.

Mount the coils at right angles to one another to minimize intercoupling. Any small metal box can be used. One amateur

made his filter inside a Band-Aid box. The capacitors should be soldered directly onto the lugs of the coils. Install the filter as close as possible to the antenna terminals of the receiver. If two tuned circuits are used, tune them one at a time for minimum strength of the interfering signal. If a series/parallel combination does not wipe out the interference, the problem is not in the antenna system.

## THE LAZY MAN'S WAVETRAP

Often, when the frequency of an interfering signal is known, it can be tuned out with a simple but ingenious device, the quarter-wave stub. It is based on the theory of (1) a shorted piece of transmission line and (2) an open piece of transmission line.

In Fig. 1-9, we see first that the voltage and current on a piece of transmission line are 90° out-of-phase with each other. A shorted line naturally has maximum current and minimum voltage at the point of the short. Since the voltage and current standing waves are, by nature, sinusoidal, we find that, exactly a quarter wave away, the voltage is high and the current low. This, by definition, is a high impedance, but only for the frequency at which the line is a quarter-wave long. For other frequencies the line is a near short circuit.

Now look at an open stub. No current can flow at the open end. At the other end, a quarter wavelength away, the voltage is low and the current high. A quarter-wave stub that is open-circuited shorts out the resonant frequency but doesn't affect other frequencies.

How to apply it? Case number 1. The XYL complains that she hears your 2-meter rig on the TV when she is watching her favorite channel. You discover that the 2-meter band is an image frequency on that particular channel. Cut a length of

**Table 4-1. Slug Tuned Coil Forms.**

| Miller Part No. | Available Inductance (mH) | Miller Part No. | Available Inductance (mH) |
|---|---|---|---|
| 4201 | .3 to .58 | 4205 | 10 to 25 |
| 4201-A | .55 to 1.1 | 4206 | 20 to 55 |
| 4202 | 1.0 to 2.5 | 4207 | 50 to 140 |
| 4203 | 2.0 to 5.5 | 4208 | 120 to 330 |
| 4204 | 5 to 12 | 4209 | 310 to 860 |

twinlead to a quarter wavelength at 2 meters, as calculated from the basic antenna formula (Chapter 1). Connect it to the antenna terminals of the TV set. Then prune the twinlead a quarter inch at a time until there is no more interference. Lastly, show the XYL what a genius you are.

Case number 2. You get a gripe from your father-in-law, who never did think you were worthy of his daughter, that your 75-meter rig comes in on his police monitor. You know he uses the radio only to listen to the police channel. Cut a quarter wave of coax (the same kind he uses on his antenna) to the police channel frequency. Short one end and connect the other end to the antenna jack of his monitor. You will have to invest in a coax connector and tee adaptor. This should not bother the frequency to which it was cut, but should wipe out anything else.

These are just two examples of how a quarter-wave stub can be applied. Chances are the open stub will be most often used, but it is well to be aware of both. It's also well to remember that half-wave shorted stub acts like a quarter-wave open stub, and that a half-wave open stub acts like a quarter-wave shorted stub.

# Chapter 5

# Tuning and Pruning

Pruning is the fine-tuning process whereby the antenna is brought to exact resonance. While satisfactory results can often be realized by simply cutting your antenna to the length determined by the basic formula, variations in resonant frequency brought about by differences in ground conductivity, the velocity factor of the particular kind of wire being used, and antenna height can throw the formula off. Most amateurs are satisfied with a 2:1 SWR. However, when the SWR is 2:1, 10% of the power going to the antenna is being reflected back and dissipated in the plate of the transmitter. If the final tubes are being run close to their limit, this can shorten tube life. Furthermore, low-pass filters only work as specified when the SWR is close to unity.

## BEFORE YOU PRUNE

Before trying to prune your antenna, connect the transmitter and measure the SWR over the portions of the band you intend to use. If the SWR is less than 1.5:1, leave well enough alone. Antennas intended for wideband use should be resonated in the center of the band. End-fed antennas intended for multiband use should be resonated at the low end of the lowest band to be used.

If you decide to prune your antenna, the obvious first step is to determine where it is resonant. Then you will at least

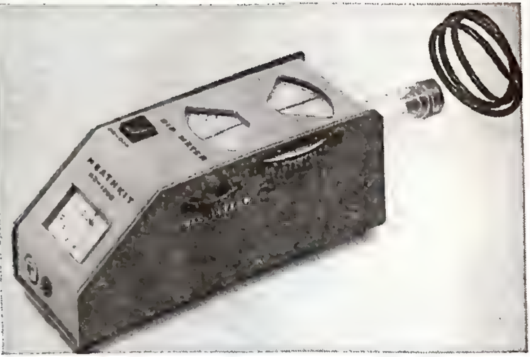


Fig. 5-1. A dip wavemeter couples into a circuit merely by proximity. Couple as lightly as possible to avoid detuning the circuit being measured. Unless you are familiar with the instrument being used, don't rely too heavily on its frequency calibration. The broadband coverage of these meters precludes precise calibration of any model. Photo courtesy Heath Company.

know which way and how far to go. There are two simple methods of determining your antenna's resonant frequency (without expensive instruments). You can spot the resonance on a dip wavemeter (Fig. 5-1), or you can fire up your transmitter at several frequencies and measure the SWR. Each method has its advantages and its disadvantages. The first minimizes interference on the band but gives a broader indication. The second is more precise but since you're transmitting for the few seconds it takes to measure the SWR, there is more potential interference. End-fed antennas can be measured only with a dip wavemeter; inverted vees should be measured by reading SWR. Dipoles can be measured either way.

## DIPOLE RESONANT FREQUENCY

Use the dip wavemeter method to resonate an antenna known to be far off-frequency. This immediately tells you whether the antenna must be lengthened or shortened.

### Dip Wavemeter Method

1. Stretch out your antenna near the ground at a height where you can reach it. Remove the coax (and the balun if you're using one).

2. Connect the two halves together with a few turns of wire. The number of turns isn't too critical at lower frequencies. I find one turn plus one for each ten feet of wire allows enough to couple into the antenna without too great a change in its resonant frequency.
3. Couple the dip wavemeter into this coupling coil and tune for an indication. Then, unless you're very sure of the dip wavemeter's accuracy, spot it precisely on your receiver dial.

### SWR Method

1. Install your antenna in its operating position and connect your transmitter. Install a reflected-power meter.
2. Tune up the transmitter, preferably with reduced power, and measure the SWR at 10-kHz intervals through the band. SWR will approach unity at the antenna's resonant frequency. If it appears that the resonant frequency is outside the band, change the antenna length, longer to reduce its frequency and shorter to increase its frequency, until you find a resonance within the band.

## INVERTED V RESONANT FREQUENCY

Since the apex angle of an inverted vee affects its resonant frequency, it must be measured in its operating position. For this reason, it is not practical to use the dip wavemeter method unless you like to climb. Use a reflected power meter and follow the steps specified for a dipole.

## END-FED RESONANT FREQUENCY

The resonant frequency of an end-fed wire cannot be measured with a reflected-power meter due to the effects of the coupler circuits.

### Dip Wavemeter Method

1. Stretch out the antenna, preferably in its operating position.
2. Connect the end of the antenna to ground through a small coil. Use the same number of turns as described for dipoles.

3. Couple the dip wavemeter into the coil and tune for resonance. The indication at the 1/2-wave resonant frequency will be relatively weak. Strong indications will occur at 1/2 and 1 1/2 times the 1/2-wave frequency.
4. If necessary, spot the dip wavemeter frequency on your receiver dial.

## 1/4 WAVE GROUND PLANE RESONANT FREQUENCY

Use the previous method to measure 1/4-wave ground planes. Strongest indication will be at the 1/4-wave frequency. Ground plane antennas (1/4-wave) also can be measured with a reflected power meter, using the same procedure as described for dipoles.

## ZEROING IN

Having determined where your antenna is resonant, the next step is to put it where you want it. You should strive for the center of the particular portion of the band you intend to operate. For example, a Novice setting up an 80-meter dipole should resonate it at 3725 kHz. If CW nets are the prime interest of a General Class amateur, he might aim for 3650 kHz. MARS people would want to hit the high end of the band. Resonate a multiband wire in the neighborhood of 3520 kHz.

Knowing where your wire resonates, and where you want it to resonate, will give you a frequency difference. That is, you will know how far and in which direction to change your antenna length. Lengthen the wire to lower its resonant frequency; shorten it to raise its resonant frequency. Table 5-1 gives you the number of inches per kHz to change the antenna length for each band from 160- thru 10-meters.

Let's assume that a Novice finds his antenna is resonant at 3.65 MHz. That means he is 75 kHz off. From Table 5-1, we find he must change the length of his antenna by $75 \times 0.4$, or 30 inches. If he is using a dipole, he must change each half of his antenna by 15 inches in order to make an overall change of 30 inches and still keep his antenna symmetrical.

Another example: My antenna, an 80-meter, end-fed wire tuned up nicely on 80, but was very difficult to resonate on 20 and 15. Checking it with a dip wavemeter indicated that its resonance was up around 3760 kHz. Excellent for 80; the tuner could resonate it OK on 40, but on 20 it would tune to a low SWR

Table 5-1. Antenna Inches/kHz

| Band | Inches kHz |
|---|---|
| 160 | 1.64 |
| 80 | 0.4 |
| 40 | 0.11 |
| 20 | 0.028 |
| 15 | 0.01 |
| Citizens Band | 0.0076 |
| 10 | 0.007 |

but drew relatively little power from the transmitter. Ideally a multiband wire should resonate on a frequency in the lowest band used that is harmonically related to the center of the highest band. For instance, if the antenna were to be used 80, 40, 20, and 15, it should resonate on the 80-meter-frequency subharmonic multiplying up to 21.125 MHz, or 3.521 MHz. Thus, I had to lower its resonant frequency by 239 MHz., which meant splicing on $239 \times 0.4 = 95.6$ inches. That was close to eight feet of wire. Once spliced on, the antenna loaded up like a dream on all the bands mentioned.

The methods given in these examples are suitable for dipoles, inverted vees, and any single-conductor, end-fed antennas, including quarter-wave ground planes. Note that 5/8 wave antennas don't need pruning since they're not resonant in the first place.

Prune a multiple-band antenna on the *highest* frequency first and work your way down, treating each dipole separately. Trap antennas should be pruned on the higher frequency first, changing only the length of the innermost wires. If more than one pair of traps is used, work your way down, one band at a time, until you reach the lowest frequency so that you prune the outermost sections of wire last. See Fig. 5-2.

## TUNING WITH ANTENNA COUPLERS

For the beginner having no test instruments, initial tune-up of a high-impedance antenna with a coupler can be a stinker. To do it right, you need: (1) a reflected power meter (2) a dip wavemeter or a receiver with a good S-meter circuit and (3) a bit of patience. Once the initial tune-up is accomplished, the coupler is fairly easy to use. Assuming of

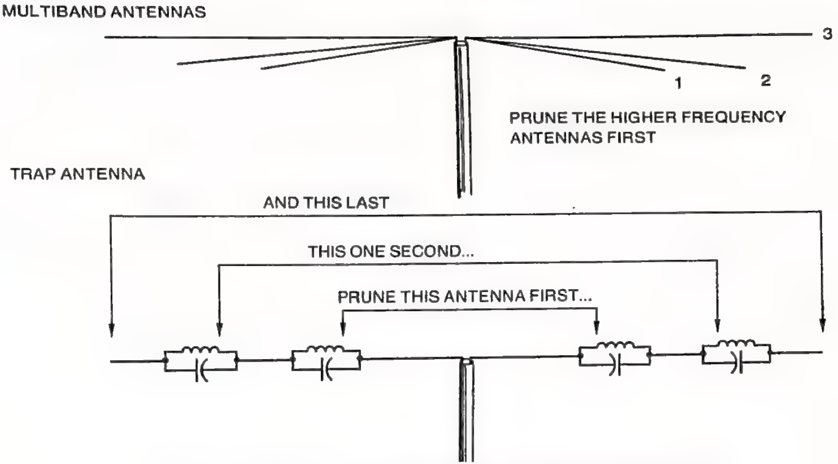



Fig. 5-2. For either type of antenna, always prune the higher frequency portions first. With the trap antenna, remember that each pair of traps represents the end of an antenna section, with the higher frequency sections being closest to the feed lines.

course that the wire, if resonant, has been resonated at the proper frequency. Tune-up procedure for random-length or restricted-space antennas is much the same, but just a bit touchier than that for resonant antennas.

With your antenna in its operating position, mount the coupler as close as possible to the point where the wire enters the shack. You may even consider having the feed-through insulator come directly into the coupler, thereby keeping the feed-end of the antenna completely protected. Others prefer to enter the coupler through a high-voltage insulator on top, in order to have better access to the end of the wire.

Connect a coaxial lightning arrestor at the coax entrance point, and provide the best practical ground connection. After installing the lightning arrestor, connect your SWR meter, then your antenna switching relay (if using separate transmitter and receiver). Figure 5-3 illustrates these connections.

**L-Network Tuners (The Lunch Box)**

1. Tune the receiver to a weak signal at or near the center of the band. Adjust the tuner to obtain maximum signal strength.

OR

1. Set the capacitor on the coupler to midrange; couple in the dip wavemeter and check for resonance.

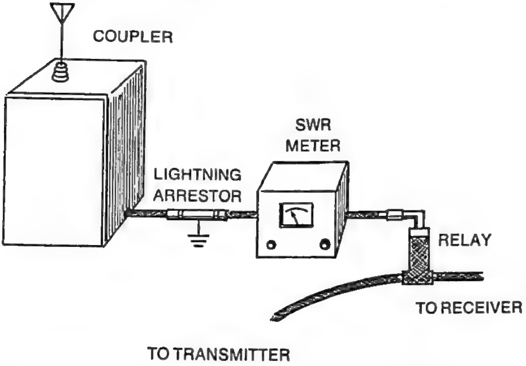



Fig. 5-3. Basic connections for tuning up an end-fed antenna system.

If you find the coupler resonating to the approximate center of the band with the capacitor set at midrange, well and good. The next step will be fine-tuning with the transmitter. But, if the tuner does *not* resonate to the center of the band, proceed as follows:

For circuits resonating *above* the desired frequency, add a mica capacitor in parallel with the variable capacitor. The amount of capacity to be added must be determined by trial and error. Change the value in 10 pF increments until the tuner resonates where you want it.

For circuits resonating *below* the desired frequency, short out one turn of the coil and recheck. Continue by shorting out additional turns one at a time until the tuner resonates where you want it.

Once you have the midrange point of the tuner where you want it,

2. Set the transmitter loading where it would normally match a 50-ohm load. If a Cantenna is available, tune up the transmitter at low power into the Cantenna, then connect the transmitter to the coupler. Do not change the transmitter loading.
3. Key the transmitter still with reduced drive and measure the SWR.
4. With the SWR meter set to read reflected power, key the transmitter and adjust the capacitor in the coupler for minimum reflected power with maximum loading of the transmitter.

   NOTE: *Minimum reflected power does not necessarily occur at the same point in the tuning range as maximum loading. Adjust for the best compromise.* With a little practice, you can realize close to full forward power with a near undetectable SWR.
5. Re-peak the tuning and loading capacitors in the transmitter.

You're on the air! From here on, changes of frequency within the band should require only a slight adjustment of the capacitor to keep a very low SWR.

**Pi-Network Tuners (Pi in the Bread-Box)**

Resonate your antenna, unless you're using a nonresonant wire. Set the input capacitor to the approximate capacity shown in the Table 5-2. These values aren't too critical, and

you can safely estimate the amounts by mere proportion of the maximum capacity.

1. Tune your receiver to a weak signal in the center of the band, and tune the output capacitor (antenna end) for maximum sensitivity.

OR

1. Couple a dip wavemeter into the coupler coil; set the dip wavemeter to the center of the desired band and tune the output capacitor for a resonance indication.

If you do not get a resonance indication, or if the indication approaches but does not go through a null indication, adjust the position of the tap in the inductor until you achieve the desired resonance.

2. Set your transmitter where it normally matches into a 50-ohm load. If in doubt, tune it into a Cantenna. Connect the transmitter to the coupler.
3. Key the transmitter and measure the SWR.
4. With the SWR meter set to indicate reflected power adjust the output (antenna end) capacitor foı minimum SWR.

   *CAUTION: Never attempt to adjust a tap on the coil while the transmitter is keyed.*

   NOTE: *The point in tuning that shows minimum SWR is not necessarily the point giving maximum forward power. Adjust the tuner for the best compromise.*

## INDOOR AND NONRESONANT ANTENNAS

An antenna conductor not naturally resonant must be made resonant to radiate a signal efficiently and to prevent

Table 5-2. Pi Network Capacitance.

| Freq. MHz | C pF |
|---|---|
| 3.6 | 884 |
| 3.8 | 838 |
| 4.0 | 795 |
| 7.15 | 445 |
| 14.125 | 225 |
| 21.125 | 150 |
| 27(CB) | 118 |
| 29 | 110 |

burning out the final tubes or transistors. Generally, this calls for a coupler or other matching device. Resonating a random-length wire is not all that difficult if certain principles are known and acted upon.

- A half-wave wire, if shortened, appears capacitive at the center; if lengthened, it appears inductive at the center.
- A quarter-wave wire, fed at the end, shows similar characteristics. That is, if too short, it appears capacitive; if too long, inductive.
- An antenna that presents a capacitive load can be resonated with a series inductor; an antenna that presents an inductive load can be resonated with a series capacitor.
- Either type can be corrected by making it part of a tuned circuit, adjusting the L or C of the tuned circuit to resonate the whole system.
- A naturally resonant antenna works better than one that has to be artificially resonated.
- An outdoor antenna works better than an indoor one.
- The higher up your antenna is, the better.

Generally speaking, most nonresonant antennas are used in the 3.5- and 7-MHz bands by amateurs who are city dwellers, unable to erect full-size antenna systems. In such a case it is best, if at all possible, to have a quarter wavelength of antenna, even if it has to be distributed all around the ceilings of your apartment. An antenna that is about a quarter-wavelength long can sometimes be fed directly at the end from the low-impedance output of a transmitter. The antenna can be measured and pruned in the same way as a half-wave, end-fed wire. It is better, however, to feed it through a series-tuned circuit.

Resonate the antenna conductor, if possible, then measure the SWR. If the match is not to your liking, add the series tuned circuit, as shown in Fig. 5-4, and tune for minimum SWR, with your transmitter set for a 50-ohm load.

To determine values of L and C, begin with the formula:

$$LC = \frac{25330}{F^2}$$

where F is the frequency in megahertz, L the inductance in microhenries, and C the capacity in picofarads. If you know the conductor is more than a quarter wavelength, use less inductance or more capacity; if the conductor is less than a quarter wavelength, use more inductance or less capacity. Actual values will depend upon the individual characteristics of your antenna, and so cannot accurately be predicted here. For a starter, though, we offer capacitance values with Fig. 5-4 to resonate a few of the B&W inductors to 80- or 40-meters, but keep in mind that your antenna will change the tuning.

Values have been given only for the lower frequency bands on the assumption that the average apartment dweller can squeeze in antennas for the higher bands, unless they are living in a closet.

Nonresonant wires can be matched, as said previously, by making them part of a parallel-tuned circuit. They can also be resonated with a pi network, although the individual characteristics of the antenna will change the inductance values. Both arrangements appear in Fig. 5-5. Pi in the Bread-Box, for example, can match anything from a whip to a resonant line with a little trial-and-error effort. With any short-length or "loaded" antenna, it is well not to shield the tuning coil as the feed-end of the antenna, including the coil, does much of the radiating. It is well, however, to insulate the coil lest some visitor discover that it contains a very high voltage.


| B & W | L μH | 80-M C pF | 40-M C pF |
|---|---|---|---|
| 3019 | 36 | 51 | 13.8 |
| 3022 | 17 | 111 | 30.2 |
| 3023 | 67 | 27.2 | 8.0 |

Fig. 5-4. This series-tuned circuit can be added to a quarter-wave antenna to improve SWR. The antenna conductor largely determines the required inductance and capacitance, but typical values are given of or 80- and 40-meters.

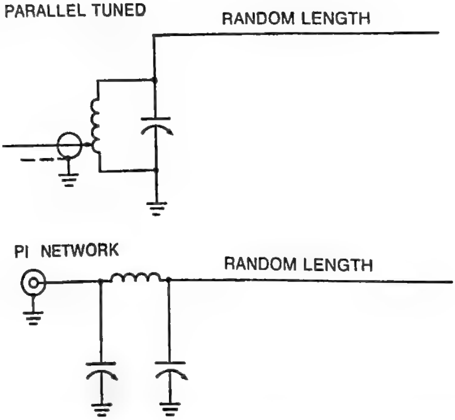



Fig. 5-5. A random length wire can be matched with either of these two circuits, though the pi-metwork configuration is more susceptible to inductance variations.

It is well, also, to point out that very short antennas, such as whips, are resonated simply by inserting a series inductor. Further details are described under the heading in this chapter of tuning mobile antennas.

## THE SHORTED STUB

Here is a handy device that, while its application is limited to relatively narrow deviations in frequency, is well worth keeping in the back of your mind in case of emergencies. It was mentioned in Chapter 1 that a section of transmission line can be used to transform two otherwise unmatched impedances. Now it may well happen, especially when using a nonresonant antenna, that one of the two impedances is unknown, or that the impedance required for a matching-section cable is a nonexistent value. In such cases, or when the proper line simply is not available, the shorted stub is the best last resort.

It has been noted that the standing waves of voltage and current along a shorted, quarter-wave stub are out of phase with one another. Theoretically the stub has a short circuit at

one end and infinite impedance at the other. It stands to reason, then, that between the two ends any existing value of impedance can be found, including the one that will properly match your antenna to your line.

The stub, a quarter-wave long at the operating frequency, is connected across the feed point of the antenna as shown in Fig. 5-6. The feedline then taps into the stub at a point producing an impedance match. This point must be found by trial and error, moving the feedline from the antenna feedpoint down a bit at a time while reading the SWR, until a reading close to unity is acheived.

## TUNING A LOW BAND MOBILE ANTENNA

Better men than I have said that the initial tune-up of a mobile antenna on the low bands can be a stinker of a job. I'll admit it's a bit touchy, but so long as you have the right equipment it's not all that bad. Don't even think about trying it unless you have a dip wavemeter and a reflected power meter.

Basically, we can consider two separate procedures: resonating and fine tuning. Resonating is done with just the antenna and impedance matching coil or capacitor in place, and the coax from the transmitter *not* connected. Fine-tuning is done with the transmitter, aided by the reflected power meter.

### Resonating

1. If the antenna is capacitively matched, connect a one-turn loop of wire between the antenna feed point

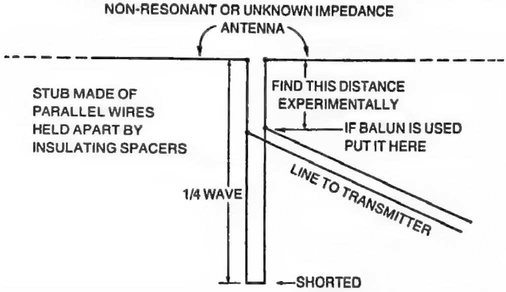



Fig. 5-6. A shorted stub can be used to match into a nonresonant antenna of an antenna or unknown impedance. The transmission line is moved along the stub until the SWR is minimized.

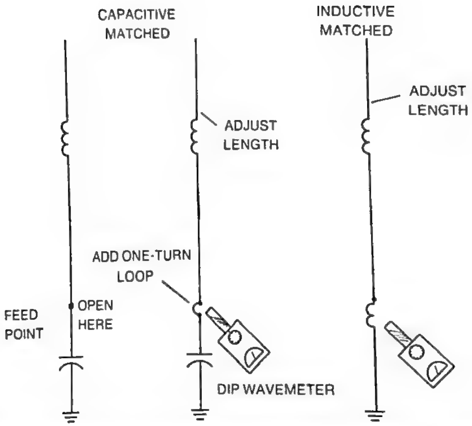



Fig. 5-7. Using a dip wavemeter to resonate either a capacitive-matched or an inductive-matched mobile antenna.

and the matching capacitor as shown in Fig. 5-7. (This loop will be removed after the antenna is resonated.) Couple the dip wavemeter into the loop.

OR

Coupler the dip wavemeter into the matching inductor of an inductively-matched antenna.

2. With the telescoping portion of the antenna fully extended, tune the tip wavemeter for an indication. If the indication is slightly below the low end of the band, well and good; if it is above the low end of the band, turns must be added to the loading coil, or the antenna must be made longer.
3. Set the dip wavemeter to the high end of the band, and adjust the telescoping section of the antenna until the dip wavemeter indicates resonance. You have now determined that the antenna can be tuned up throughout the entire band.
4. Set the dip wavemeter to the center of that portion of the band where you contemplate the most operation. Use your receiver to be sure the frequency setting is correct.

5. Adjust the telescoping section of the antenna until the dip wavemeter indicates resonance.
6. If the antenna is capacitively matched, remove the one-turn loop and reconnect the resonating capacitor. Connect the coax to the feed point.

**Fine Tuning**

1. Connect the reflected power meter to the system.
2. Tune up the transmitter with reduced power and measure SWR.
   NOTE: *For this part of the procedure, the car must be in the open, well away from any trees, buildings, or other large, grounded objects.*
3. Increase the transmitter frequency 25 kHz above the starting frequency and measure SWR; decrease the transmitter 25 kHz below the starting frequency and measure SWR. If the SWR is lower at the higher frequency, the antenna must be lengthened; if the SWR is lower at the lower frequency, the antenna must be shortened.
4. Change the antenna length 1/4 inch and measure SWR. Repeat this until SWR is lowest at the desired frequency.

# Chapter 6

# Accessory Equipment

Enough test equipment related to antenna work is available that an entire book could be written on that subject alone. For amateur use, however, a few key instruments measure everything required to get the job done, and these can be homemade if necessary.

## SWR METERS

Perhaps the most important and the most common is an instrument for measuring standing wave ratio. SWR gives so accurate a picture of the overall performance of an antenna that many amateurs constantly have one in the line. With this instrument an antenna can be pruned to near theoretical perfection. Any problems affecting antenna performance immediately cause an abnormally high reading. When all is functioning normally you know that all the power being sent to the antenna is staying there rather than being reflected back to the transmitter.

Standing wave ratio is measured by comparing the forward and reflected power. Amateurs use three general categories of instruments to make these measurements: bridge circuits, reflectometers, and RF power meters.

### The Bridge Circuit

The basic bridge, shown in Fig. 6-1, consists of four resistances connected in two parallel, equal branches having a

sensitive meter connected between the midpoints of the two branches. If the two branches truly are equal, a voltage applied across them will appear as an identical voltage at each midpoint. Consequently no *difference* of potential exists to drive the meter. If, however, one of the four resistors is not equal to its counterpart in the other branch, unequal currents flow through the two branches, a difference in potential exists between the two junction points, and the meter shows that difference.

To apply this principle to antenna work, we must adapt the bridge, by making the indicator a sensitive RF voltmeter, by adjusting the resistances to balance the bridge at the transmitter output impedance, and by then measuring the antenna impedance, using the transmitter as a source. The principle of this circuit, shown in Fig. 6-2, is that the meter reading will be proportional to the amount of unbalance between the transmitter impedance and that of the load. The meter can then be calibrated directly in SWR, using the formulas in Chapter 1.

While this method works, is reasonably accurate, and is used quite often in the field, it has disadvantages. First, the power applied from the transmitter must not exceed the combined ratings of R1 and R2. Second, since R3 is in series with the transmitter, the instrument cannot be left in the line constantly as R3 alone will absorb 50% of the power.

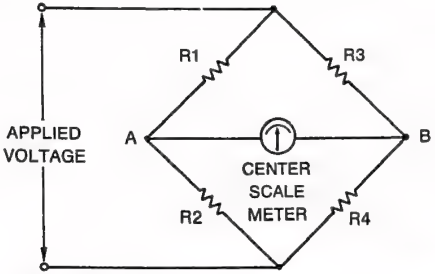



Fig. 6-1. Basic bridge circuit. If R1=R3, and if R2=R4, the bridge will be balanced. Current through R1-R2 and R3-R4 is exactly equal. Therefore, the voltages at points A and B are equal, and no current flows through the meter. The least change in any resistor unbalances the bridge causing the meter, a zero-center movement, to indicate in the appropriate direction.

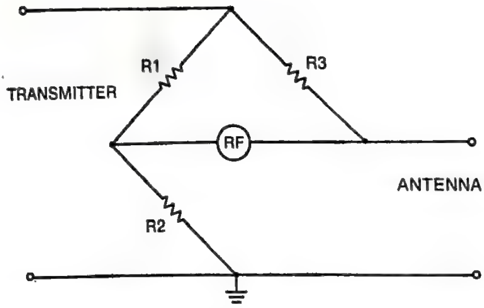


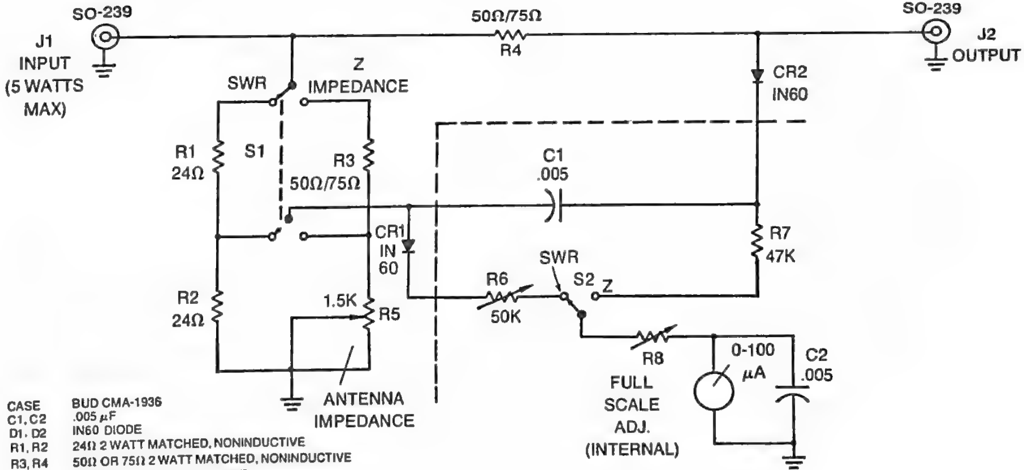

Fig. 6-2. Application of the basic bridge to antenna work. The antenna becomes one leg of the bridge, and the transmitter provides the signal at the operating frequency. The meter must be able to measure RF voltages.

There is, however, one tremendous advantage to circuit for the experimenter who expects to do a considerable amount of antenna work. A slight modification of the circuit makes R1 and R3 of equal resistance and R2 variable. By adjusting R2 for a null in the meter reading, then reading its resistance from a previously calibrated dial, the exact impedance of an unknown antenna can be measured at the transmitter frequency.

These principles all can be applied to a single, easy-to-build instrument able to measure either SWR or antenna impedance. The schematic diagram and parts list appear in Fig. 6-3. While some degree of tolerance always exists in resistance values, it is of utmost importance that resistors R1 and R2 match each other exactly. Also, R3 must exactly match R4. The latter two resistors should each be of a value near the impedance of your coax.

Build the bridge in a sloping-front metal cabinet such as the Bud CMA-1936. Keep all leads as short as possible, but avoid any stray coupling between the arms of the bridge. Components within the dotted line should be shielded.

Potentiometer R8 sets the meter to full scale. Switches S1 and S2 select either SWR measurement or impedance measurement. Potentiometer R5 should have a dial calibrated to show its resistance which, when the bridge is balanced (indicated by a null on the meter), will exactly equal the unknown impedance.




| | |
|---|---|
| CASE | BUD CMA-1936 |
| C1, C2 | .005 µF |
| D1, D2 | IN60 DIODE |
| R1, R2 | 24Ω 2 WATT MATCHED, NONINDUCTIVE |
| R3, R4 | 50Ω OR 75Ω 2 WATT MATCHED, NONINDUCTIVE |
| R5 | 1.5K NONINDUCTIVE 2 WATT |
| R6 | 50K |
| R7 | 47K 1/2 WATT |
| R8 | 50K |

Fig. 6-3. A combination antenna impedance and SWR meter. The beauty of this instrument is that you can measure the impedance of an unknown antenna directly.

To test the instrument, set it to SWR and apply sufficient power from the transmitter (not more than five watts) to obtain a full-scale indication on the meter, within the range of R8, and with no load connected to J2. Then connect to J2 a resistor exactly equal to R2. The meter should read zero. A reading on the meter indicates that either the resistors are not matched or there is stray coupling within the instrument.

To measure SWR, connect the transmitter to J1 and apply four or five watts. With switches S1 and S2 set to SWR, adjust R6 for a full-scale reading on the meter. Then connect the antenna and note the meter reading. If the meter is calibrated 0 to 1, the reading is the coefficient of reflection (K), from which SWR can be calculated by plugging it into the following formula:

$$\mathrm{SWR} = \frac{1+K}{1-K} \text{ where K is the reflection coefficient.}$$

To measure antenna impedance, set the selector switches to impedance (Z), and apply power from the transmitter as before, with the antenna connected. Adjust R5 for a null in the meter reading. Then read the antenna impedance directly from the dial on R5.

While the bridge just described can be very handy to have around, it does have its disadvantages. First, it can't be left in the line permanently unless you like the smell of roasted resistors, which would certainly result from hitting it with full transmitter power. Second, even if the transmitter had a low enough power rating for the resistors, half of the power from the transmitter would be lost in R1 and R2, and half of the remaining power would be lost in R4. What I'm saying is, leaving this thing in the line doesn't make for the highest in efficiency.

**The Reflectometer Circuit**

Far more popular for SWR measurement, and perhaps the most popular type of SWR instrument in use, is the reflectometer. A simple reflectometer consists of a simulated section of the transmission line in which two directional couplers read the forward or reflected power respectively. The directional coupler is an extremely simple circuit mechanically, although the principle is based on some

horrendous mathematics. It consists of a conductor run parallel to the center conductor of the simulated section of transmission line. The electrical and mechanical configurations appear in Fig. 6-4. One end of the conductor is connected to a resistor of the approximate value of the line; the other end is connected to an RF voltage indicator. The nature of the beast is such that it responds only to power passing through the center conductor in a direction from the diode end toward the resistor end.

In the reflectometer, the two directional couplers are set opposite in direction to one another, and selected by a switch. First the forward power is read and the RF indicator set to read full scale. Then the switch is thrown to the other coupler and reverse power is indicated proportionally on the meter.

Instruments of this type are widely available, thanks to the popularity of CB, and are relatively inexpensive, costing as little as $15 to $20. Commercially made instruments are calibrated directly in SWR and in reflected power. With nothing to wear out, they last a lifetime, can be left in the line with no appreciable loss, and allow constant monitoring of antenna behavior.

An instrument next in popularity to the simple reflectometer uses a toroidial transformer with a single-turn primary to couple into a direction-sensitive circuit which not

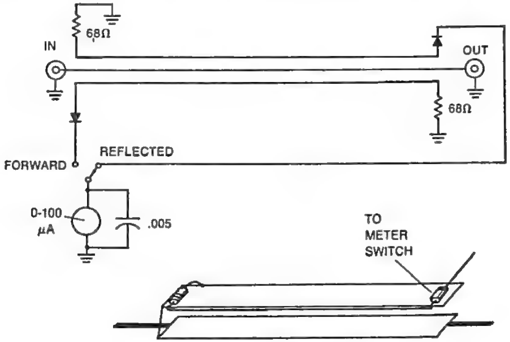



Fig. 6-4. A simple reflectometer circuit and its mechanical layout. Only one pickup loop is shown. The other should be located on the opposite side of the transmission line center conductor.

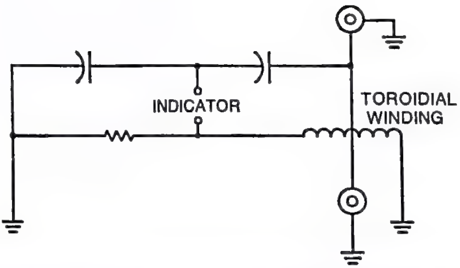



Fig. 6-5. This is the basic reflectometer circuit. On a transmission line without standing waves, the voltage at the capacitive divider will be out of phase with the current-derived voltage in the other leg. Thus, no indication appears between the two legs.

only measures SWR but also gives direct, quantitative forward-power readings. Since this instrument uses additional parts, it is more difficult to calibrate than its nearest competitor; however, the circuit is less sensitive to variations in frequency. Heathkit features a model with the meter unit remote from the detection unit.

Figure 6-5 is the basic circuit for this typeRF power meter. Actual part values depend on the line impedance and on the sensitivity of the meter movement. The two capacitors form a voltage divider in which the voltage is in phase with the transmission-line voltage at the point where the instrument is inserted. The voltage across the resistor, however, is in phase with the *current* in the transmission line. If the line is properly matched, that is no standing waves, the voltage across the capacitor is out of phase with the voltage across the resistor and there is no meter reading. If the transformer secondary is reversed, a meter reading is obtained proportional to both voltage and current, which represents power. Thus the instrument can be used to measure real-power going to the antenna, or it can be used to measure SWR.

Figure 6-6 provides a practical circuit for a reflectometer which any enterprising ham can build without too much difficulty. For greatest accuracy, capacitors C3 and C4 must be matched, as must resistors R1 and R2. The secondary of T1 is wound on an Amidon T-68-2 toroid, which can be purchased from Amidon Associates at 12033 Otsego St., N. Hollywood, CA, 91607.

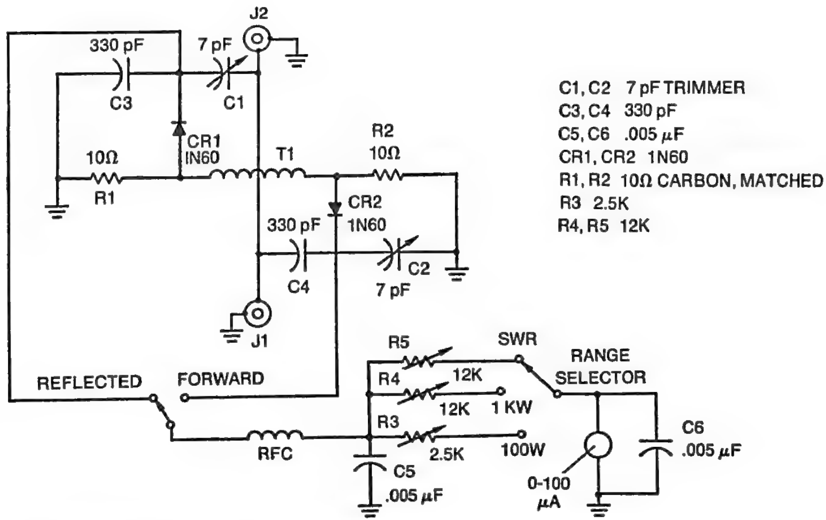



Fig. 6-6. This practical reflectometer circuit measures both SWR and power. Construction should be symmetrical, and the meter circuit should be kept awav from the RF circuits.

Initial adjustment for this circuit is a bit involved but not impossible. You will need a dummy load, such as the Heath Cantenna. Connect the transmitter to J1, and the Cantenna to J2. Then follow this step-by-step procedure.

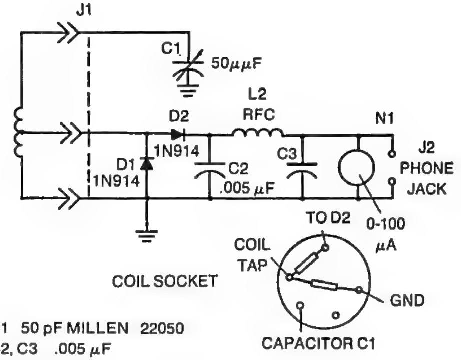
1) Set the meter switch for forward power, and the range selector switch for SWR. Adjust R5 for a full-scale reading, with the transmitter keyed at full power.
2) Set the meter switch for reflected power and adjust C1 for a zero reading on the meter. The meter may not quite null yet.
3) Switch the connections to the transmitter and the Cantenna.
4) Set the meter switch for forward power and adjust C2 for a zero reading on the meter.
5) Go back to the beginning and repeat the procedure until the meter nulls to zero in both directions.
6) Set the power range pots by measuring the actual RF voltage at the Cantenna with an accurate RF voltmeter. Calculate the power then set the appropriate power range pot for the proper reading on the meter.

**The Field Strength Meter**

A field strength meter is one of the simplest instruments to build and, for those who like to experiment with antennas, one of the handiest. It consists of a sensitive meter connected to the output of a detector. Some of the simpler models are untuned; the better ones have tuned inputs. A method is usually provided to adjust the meter for an on-scale reading. Then, so long as antenna length and other circuit parameters are unchanged, an accurate indication of relative field strength is provided.

This meter, shown schematically in Fig. 6-7, can be built in any convenient-size Minibox. Including the tuned circuit improves sensitivity, and the phone jack allows monitoring of the signal. Either can be left out, and you still will have a useful instrument.

The coils are wound on a Millen 45005 form, which plugs into a five-pin tube socket. An illustration of these handy forms appears in Fig. 6-8. While any handy 50 pF variable capacitor can be used, Millen makes one, #22050, which is compact, not




C1 50 pF MILLEN 22050
C2, C3 .005 μF
D1, D2 1N914
J1 5-PIN TUBE SOCKET
J2 PHONE JACK
L1 MILLEN 45005 FORM WOUND FOR BAND PREFERED
L2 10 mH RF CHOKE
M1 100 μA METER

| | | |
|---|---|---|
| 1.5- to 4.5-MHz. | 124 TURNS | 30 WIRE, TAP AT 31 TURNS. |
| 3.0- to 8.2-MHz. | 45 TURNS | 30 WIRE, TAP AT 11 TURNS. |
| 6.0- to 18-MHz. | 24 TURNS | 20 WIRE, TAP AT 6 TURNS. |
| 13- to 35-MHz. | 9 TURNS | 20 WIRE, TAP AT 2 1/4 TURNS. |
| 30- to 85-MHz. | 4 1/2 TURNS | 12 WIRE, TAP AT 1 1/4 TURN |
| 75- TO OVER 200-MHz. | 1 TURN | 12 WIRE, TAP AT 1/4 TURN. |

Fig. 6-7. A practical field strength meter including a tuned circuit and phone jack output. Either of these features can be eliminated if desired.

too expensive, and easy to mount. Capacitor and coil form can be ordered from James Millen Co., 150 Exchange St., Malden, Mass., 02148.

Frequency ranges are approximate; exact ranges will depend on parts layout, wiring capacities, etc. Mount the diodes right on the coil socket. Then, if the capacitor is mounted directly beneath the socket, providing the minimum possible lead length, you should come pretty close to the specified frequency ranges.

To calibrate the capacitor dial, you will need a calibrated signal source. Many amateur clubs can make a signal generator available. If you live in a large city, there may be an equipment rental agency nearby, or you may be able to reach

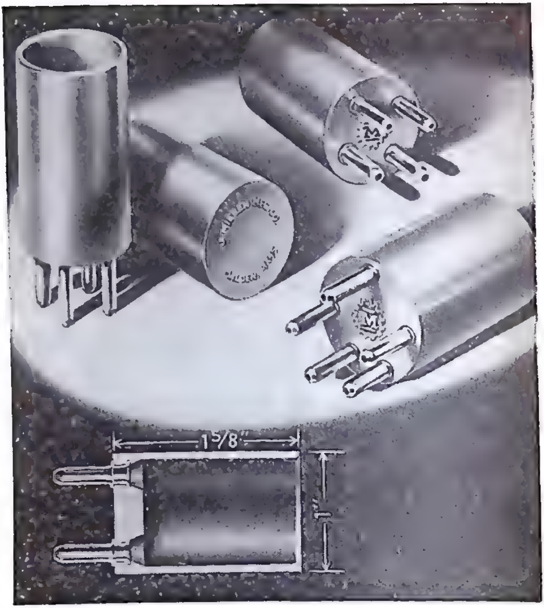



Fig. 6-8. With plug-in coil forms like these, band changing is a snap, and the same coils can be used in more than one instrument. Photo courtesy James Millen Company.

a rapport with the local school system. Then it's simply a matter of setting the generator to a known frequency, tuning it in on the meter, and marking the dial.

**The Dip Wavemeter**

Perhaps the handiest of the basic test instruments, and the super granddaddy of the signal-strength meter just described, is the dip wavemeter. Back in the days when vacuum tubes were the thing, this instrument was known as a grid-dip meter. Its big claim to fame is the ability to determine resonant frequency of an unknown tuned circuit or device. This one application makes it worth its weight in gold when you have antenna work to do. Two commercial versions appear in Fig. 6-9.

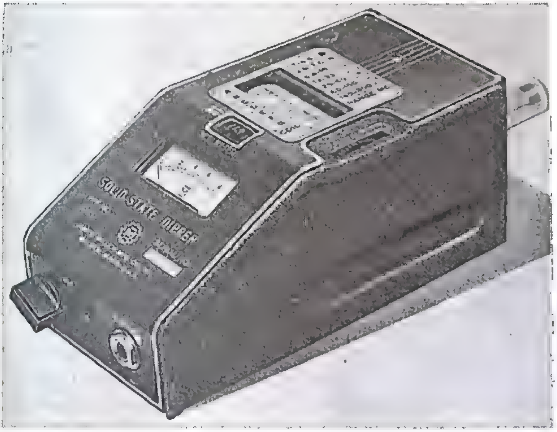



Fig. 6-9. A commercial dip wavemeter (top) and its solid-state child. Photos courtesy James Millen Company.

A dip wavemeter consists of an oscillator with accurate frequency calibration. The original beast worked on the principle that the grid current in the oscillator would decrease markedly when the instrument was coupled into any circuit that was resonant at the operating frequency of the wavemeter. Normal use involves holding the coil of the wavemeter close to the unknown circuit while slowly tuning the oscillator. The meter dips as you tune over the resonant frequency. Hence the name, dip wavemeter.

Nowadays with solid-state circuits used in the wavemeter, what do we call it? A base-dip meter? A gate-dip meter? There can be as many names as there are solid-state devices. Dip wavemeter seems to fit best.

Using the same coil-capacitor combinations used in the field strength meter, we can add an oscillator circuit and dip indicator to make a dip wavemeter. With a little planning, both the field strength meter and the dip wavemeter can be contained in the same box. The circuit appears in Fig. 6-10.

It works on this principle: Power is drawn from an oscillator when it is coupled into a circuit that is resonant at the operating frequency of the oscillator. When power is drawn from this oscillator, there is less available to be coupled into the amplifier circuit driving the meter. Thus the meter reads lower.

Resistor R1 is called out to be 100 kΩ. You may want to start with some higher value and work your way down until finding a value with which the circuit will oscillate suitably over the entire range but with minimum power drain, a characteristic that can vary with individual transistors.

Calibration is easy since the circuit is oscillating and generating a signal. All you need is a receiver that is accurately calibrated for frequency. Simply spot the meter's frequency on the receiver dial, and mark the meter dial accordingly. You will obtain a more accurately calibrated meter than is available commercially; I have yet to see a commercially built dip wavemeter with an accurate dial.

When using this or any other dip wavemeter, couple the coil into the circuit under test and tune the meter slowly—*very* slowly—until you get a definite indication. Then gradually move the meter away from the circuit under test while tuning over the frequency until the dip is barely noticeable. This light coupling gives the most accurate measurement.

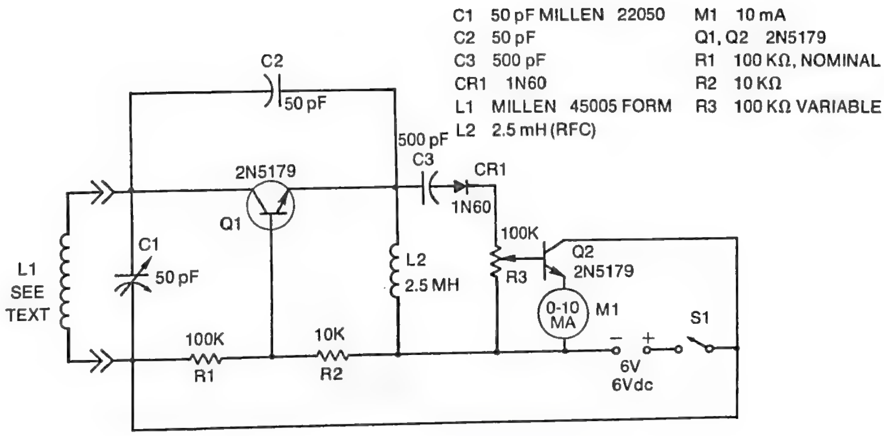



Fig. 6-10. A dip wavemeter circuit utilizing amplification in both the tuned circuit and the DC stage driving the meter. Obtain the coil winding data from Fig. 6-7.


Fig. 6-11. This commercial 50-ohm dummy load will handle 200 watts continuously, or up to 1000 watts when derated for time. A DC output provides a relative indication of the input power. Photo courtesy the Heath Company.

## THE DUMMY LOAD

Every ham station should have a dummy load. Not only can it keep you legal, but also it shows common courtesy to fellow hams. A good dummy load also provides a powerful troubleshooting tool. It's a nice feeling to be able to connect a known impedance into the line when all the theory seems to have gone out the window. Although articles have appeared over the years for building your own dummy load from scratch, it is unlikely that the money saved even remotely makes up for the time spent on the project. Most hams rely on the Heath Cantenna (Fig. 6-11). This 50 ohm load, housed in a #10 can, will handle up to 1000 watts when immersed in an oil bath. SWR below 300 MHz is no greater than 1.5:1, about as good as you'll ever work with around antennas.

# Chapter 7

# Lightning and Lightning Protection

A text on antenna systems would not be complete without some coverage on the nature of lightning and techniques for protecting equipment and property from the effects of this phenomenon. Lightning has awed mankind since long before the dawn of recorded history. In dramatic presentations, it had almost always been said to be the representation of divine action. Until Ben Franklin unraveled its mysteries, there seemed to be no protection from it. It struck randomly and without discrimination at rich and poor alike.

With the dawn of electrical knowledge came the realization of the nature of this seemingly diabolical force. Almost from the beginning, it has been associated with radio. Long before Marconi succeeded in communicating by radio, a Russian experimenter used a radio detector to deliver a warning of an approaching thunderstorm. In the U.S. another scientist used atmospheric electricity to power a crude and very dangerous system of radio communication.

## THUNDERSTORMS

The present state of electrical knowledge has lightning well defined. We know, of course, that it is the discharge of enormous electrical potentials that accumulate naturally through atmospheric action. We also know that, since any electrical current follows the path of least resistance, the

presence of a low-resistance, grounded conductor extending high into the atmosphere is an invitation to a lightning stroke. Lest the hazard be minimized, every amateur ought to be familiar with this phenomenon and should, at least, be fully aware of the magnitude of problems it produces.

Figure 7-1 should give you an idea of the wide variation in the frequency of thunderstorms throughout the contiguous United States.

Thunderstorms are comparatively rare in Alaska. As to Hawaii, having no data, I can only speculate. From what little I do know, I would imagine that thunderstorms are relatively common on the eastern sides of most islands, where rainfall is heaviest. However, if you live on Niihau, don't worry.

The relative intensity of the average storm for a given area is proportional to the frequency of thunderstorm activity in that area. We can see, then, that a degree of protection considered excessive on the West Coast would likely allow equipment on the Florida Peninsula to soon go up like a roman candle. But would the equipment on the West Coast be over-protected? Mild as storms there are, a single, direct stroke would still ruin equipment. The degree of protection, you see, is really a gamble against known odds. However widely those odds may vary, only a fool takes chances.

In 1970, a scientist at the General Railway Signal Company in Rochester did considerable research on lightning. He came up with the following statistical data:

- The voltage of a lightning stroke is about 900 thousand volts for each linear foot of the path of the stroke. (Other sources say it is limited to 30 to 300 million volts, but this author is not about to attempt any measurements to determine who is right.)
- The current can be from 4000 to 250,000 amperes, with an average of 100,000 amperes.
- The duration of a stroke is about 5 to 10 microseconds.
- The length of the path of a stroke can be up to 10 miles (52,800 feet).

If this scientist is correct in his estimation of the voltage, a 10-mile stroke discharges as much as 47 billion volts. At maximum current, this can produce an instantaneous power of 4700 trillion watts. Now, if the stroke lasted a full 10

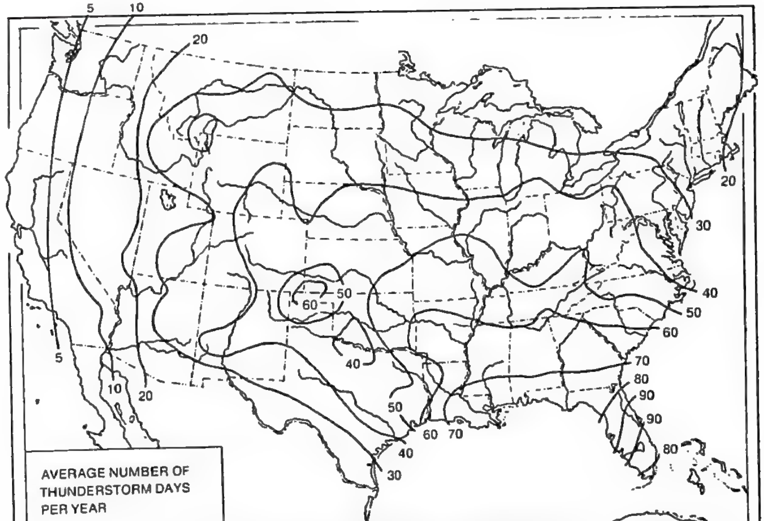



Fig. 7-1. Average number of thunderstorm days per year in the contiguous United States. Based on information from the U.S. Weather Service.

microseconds, a calculation of watt-hours will show that the power produced exceeds the electrical power used by an average American family in a month. This from one stroke.

No lightning rod, arrester, or other device can withstand the current from a direct stroke of this magnitude. To understand just how these devices protect, and to learn what they protect against, let us first understand just what is happening.

**Lightning Formation**

We all know, of course, that lightning is generally produced by a particular type of cloud. From underneath, a thunderhead appears as a low, gray, ominous-looking mass. From a distance, it looks like a tall, almost cylindrical bale of cotton. A thunderhead can tower up to 75,000 feet. Anyone who has had any contact with aeronautics will tell you that even the best of pilots steer a wide circle around a thunderhead. For, serene as thunderheads look from a distance, their interiors are an airborn hell of turbulence. Winds of 100 m.p.h. move vertically forcing raindrops up as well as down.

A very pronounced temperature gradient exists within a thunderhead. Although the temperature may be as high as 90° at ground level, it is zero at about 30,000 feet, and −60 at 45,000 feet. In the upper region, raindrops carried by the vertical winds are frozen solid. Now, you well know how easily static electricity is generated when the weather is bitter cold. In the upper portion of the cloud, an ideal condition exists for this. The ice particles, whipped around by the winds, generate enormous charges.

Charges generated within a thunderhead are carried from one end to the other by the winds. As the cloud matures, definite electrically charged zones appear. Positive charges accumulate at altitudes above the 0°F level, and a strong negative region forms at altitudes in the 0° to 32° level. Below the 32° altitude, pockets of positive charges accumulate, surrounded by some negative zones. These charges at the bottom of the cloud are mirrored by opposite charges in the ground below.

An electrical potential exists, the exact magnitude of which has never been exactly determined, at which the electrical resistance of air breaks down, a little at a time. Referring to Fig. 7-2, charges in the cloud attract opposite

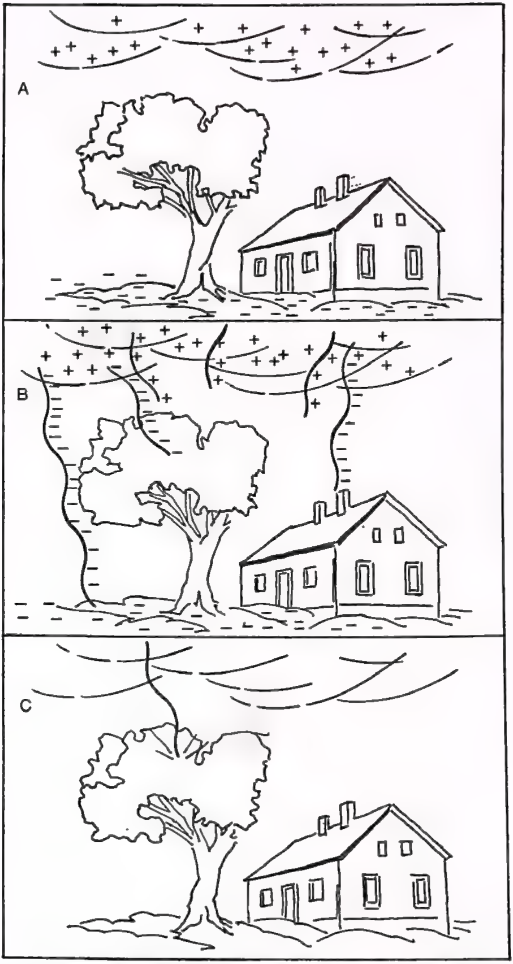



Fig. 7-2. The sequence of a lightning stroke. In A, a charge has built up between the clouds and ground. In B, probing "leader" strokes attempt to bleed off the built-up charge. When a pair of "leaders" meet, a sudden, massive flow of current results (C).

charges which accumulate in all objects below (A). When these charges approach the breakdown potential, "leader" strokes begin probing from both the ground and the cloud (B). When two leader strokes meet, a low-resistance path exists and heavy current suddenly flows (C). Often several strokes may follow this path.

**Lightning Prevention**

We now see that a charge must accumulate to a specific magnitude before lightning can strike. Fortunately for us, the very wet conditions that normally exist under a thunderhead are not exactly conducive to the accumulation of static charges. It takes just one small additional adjustment of conditions to swing the odds against a lightning stroke in our favor. That device is a lightning rod, the pointed top of a tower, or any similar, high pointed object. Anyone in the TV business can tell you that corona discharge in the high-voltage line almost invariably occurs wherever there is a sharp point. A lightning rod, being pointed, helps bleed off the electrical charges that are trying to build up in the portion of ground to which it is connected. Consequently, the potential near a lightning rod can rarely build up enough to send out a leader stroke. When it does, the stroke is sufficiently weakened for the rod to drain the entire current harmlessly to ground.

Even a greatly weakened stroke of lightning contains enough power to cream your equipment, so an additional amount of protection is needed. Furthermore, there is another threat to your equipment from lightning, one the experts seldom mention. That threat is called the ground surge.

With an electrically-charged cloud overhead and an opposite charge in the ground beneath, we can liken our situation to being on one plate of a giant capacitor. In Fig. 7-3, we see the capacitor (A) with its plates charged. The charge is evenly distributed throughout the entire area of the plates.

Now when the capacitor is discharged (B) current flows, of course, through the wire. However, it also flows from all parts of each plate to the wire. Now, the discharge path of our capacitor is the path of the lightning stroke. When a stroke occurs, current flows not only at the point of the stroke, but down out of objects in the surrounding area, and through the ground to the path of the stroke (C). This current is the ground surge previously mentioned. When a stroke hits nearby, a

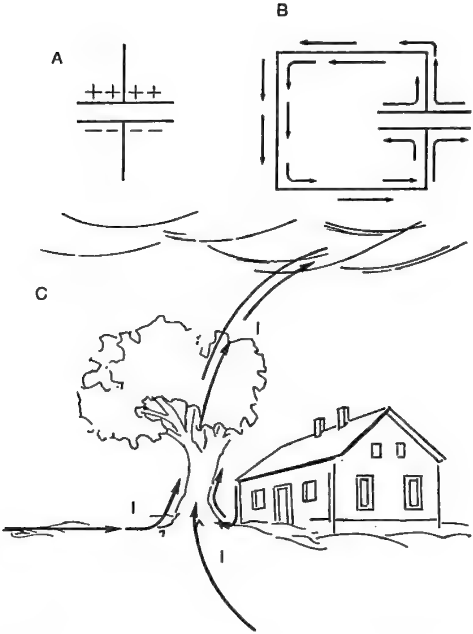



Fig. 7-3. Although the charge on a capacitor is evenly distributed, it must concentrate at the connecting wires when current flows (A and B). At C the heavy currents produced by a stroke of lightning are shown flowing into the tree, an analogy to the wire of a capacitor.

current as much as 10% of the stroke current may flow between a tower and the ground. This current can do considerable damage to unprotected equipment.

Electricity follows the path of least resistance. Even with an arrester on your antenna, the equipment in your shack may suddenly become several thousand volts lower in potential than the antenna, but not quite enough to break down the arresters. If multiple ground paths exist, current surges of considerable magnitude can occur. These heavy cross currents can be prevented if a scheme is implemented to

ensure that, at any given instant, all pieces of equipment in the shack are bonded at the same potential.

## THE PRIME GROUND TERMINAL

Radio communications shares its lightning problems with other services. In fact railroads have a far more serious problem than we do. Signal wires running for miles above ground terminate in sensitive, track-circuit-detection equipment. The risk of being wiped out exists even on a sunny day, if there happens to be a storm in progress at the other end of the line. In spite of this risk, however, railroads are able to provide sufficient protection to their equipment to make failures a rare occurance. How do they do it? Not by techniques we don't know about, but instead with lightning arresters and a good "prime ground terminal."

Each wire entering an equipment housing is protected by a lightning arrester, similar to the ones we use but of much heavier construction. Sensitive equipment is further protected by a glow discharge tube. These, as well as the chassis of each piece of equipment, are connected to the prime ground terminal. Even the frame of the equipment housing is connected to this terminal. The prime ground terminal, the *only* path to ground, connects through a very heavy conductor to a network of ground rods driven *deep* into earth ground these techniques are illustrated in Fig. 7-4. Analyzing all this, we begin to see a pattern:

- One, and only one path to true earth ground.
- Each piece of equipment connected individually to the ground path.
- Leads to ground equal in length for each piece of equipment.
- Ground connections themselves spread out and driven deep.
- Each incoming wire protected by an individual arrester, even though similar protection may exist at the other end.

### The Ground Connection

We can apply these ideas to amateur radio, although such elaborate measures are by no means popular except in high thunderstorm areas. Let's begin with the ground connection.

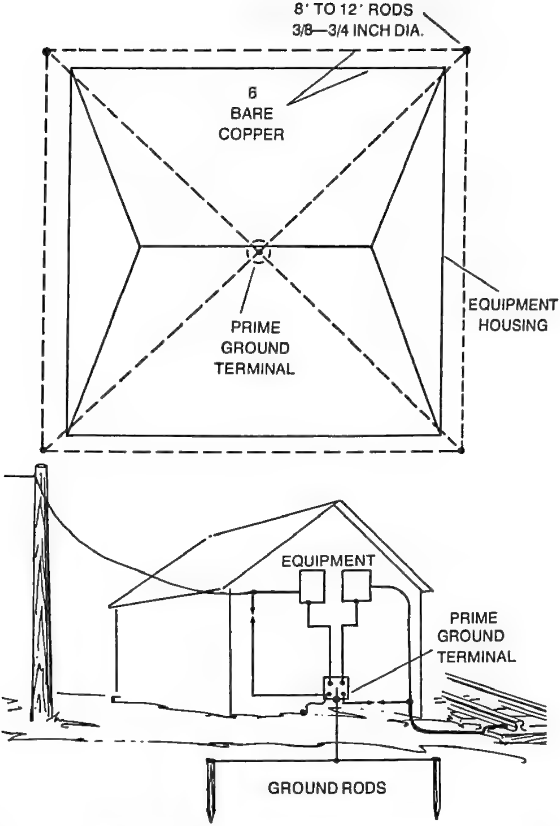



Fig. 7-4. Typical methods of arrester installation and grounding in a railway equipment housing.

In Chapter 2 we suggested buried-wire radials to improve the ground conductivity beneath the antenna. Here we are adding the idea of a deep-ground connection for lightning protection. The whole idea is to get the ground rods down to where the soil is permanently damp. If the soil conditions prevent this,

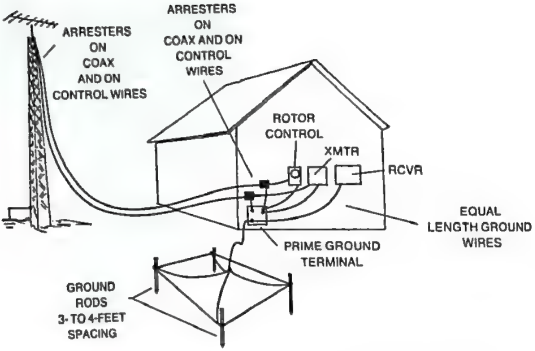



Fig. 7-5. Suggested lightning protection scheme for an amateur radio antenna installation. All lines entering the shack must have an arrester in the line. Every ground wire to the prime ground terminal must be the same length. The ground rods must be driven into moist soil, then interconnected with 10 or heavier gauge wire. Each rod must feed a separate wire to the ground wire coming from the shack.

improve conductivity by mixing a little charcoal with the soil when you bury your radials. In locations where solid bedrock appears at the surface, ground radials can be cemented down. Such extreme measures, however, are seldom necessary.

In high-risk areas, drive four or five rods, at least six- to eight-feet long, into the ground in a pattern spacing three- or four-feet apart and connected together with #10 or larger wire. Each rod then must be connected by a separate lead to the wire from the shack's prime ground terminal.

The prime ground terminal itself can be easily made by simply drilling a number of holes in a 6 × 6 inch square of 1/8 inch copper or aluminum plate. Use a #21 drill and tap each hole with a 10-32 thread. Leads from the individual pieces of equipment can be connected to lugs which are fastened to the terminal by 10-32 bolts. The downlead for the earth ground can be either soldered to the plate or bolted, preferably to the center.

### The Tower Ground

Towers or masts should be directly connected to a low-resistance ground connection. In some instances, such as

when the tower itself is the antenna, this may be impractical. We can then use a broadcasting industry practice and bring a pointed rod in close proximity to the end of a deeply driven ground rod. Figure 7-7, the base of a broadcast tower, shows one bit of poor thinking on somebody's part. It was taken on a rainy day, and I watched as water accumulated in the gap until it made a partial short putting the station momentarily off the air. This could have been prevented by shaping the arrester bars into a drip-loop as shown in Fig. 7-8.

### The Equipment Grounds

Coax, and any control or indicator wires routed any appreciable distance from the shack should be protected by arresters at the antenna. *All* wires coming into the shack from the antenna must be protected with suitable arresters, and these should be connected only to the prime ground terminal.

If all these measures are observed, relatively little need be done to equipment within the shack. Many receivers are

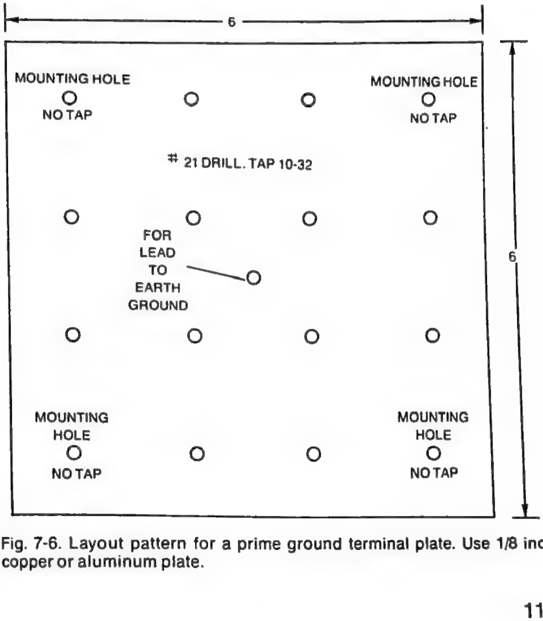



Fig. 7-6. Layout pattern for a prime ground terminal plate. Use 1/8 inch copper or aluminum plate.

Fig. 7-7. Lightening protection on a commercial radio tower. The cone-shaped area is an insulator supporting the actual radiating section of the tower. The grounded, L-shaped bar rises to within a fraction of an inch of the rod attached to the insulated section.

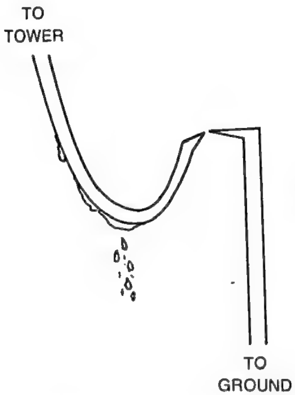



Fig. 7-8. Water drip-loop on a radio tower arrester assembly.

protected with a pair of diodes connected back-to-back across the antenna terminals. This prevents any voltage across the antenna from rising above the 0.7-volt forward drop of the diodes. In high risk areas, connecting a neon glow lamp across the *receiver* antenna terminals provides additional protection. Both these techniques are illustrated in Fig. 7-9.

To the amateur who has operated for years without trouble, these measures may seem to be extreme. The extent of protection provided should be based on your knowledge of the weather conditions where you live. Not being familiar with every existing set of local conditions, I can show only the extreme measures and allow common sense to prevail from there. Many amateurs are satisfied merely to provide a switch which can be thrown to hard-wire the antenna to ground during a storm. That's OK as long as he remembers to throw the switch every time. Murphy's Law says you'll forget it only for the wrong storm.

The urban amateur may know that a nearby church spire provides a cone of protection for a radius of twice its height. This may well protect a shack from a direct stroke, but not from ground surges. In a city, however, enough metal exists underground to allow the use of a simple water-pipe ground and coaxial arresters. This would likely suffice—until Nature decides to do things differently. At any rate, we can cite the old

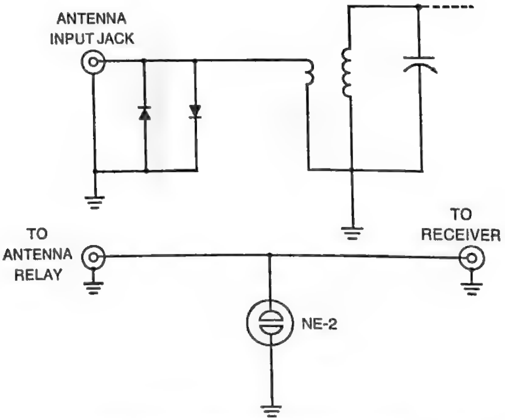



Fig. 7-9. Connections for installing back-to-back protective diodes or a neon lamp protective shunt.

maxim that it's better to be safe than sorry and point out that whether you use a lot of protection or a little, it is never a good idea to be without any.


Fig. 7-10. A church steeple or other high, grounded structure provides a "cone of protection" for a radius of twice its height. Since this is not foolproof, you'd do well to provide protection even if your station is within the "safe" area.

# Chapter 8

# Where Space Is A Problem

In all the preceding chapters we have stressed the concept of an antenna being a multiple of half wavelengths. This would, at first glance, pronounce a sentence of doom to the urban dweller who can't possibly put up a half-wave dipole. It's not all that bad. Two variations of the rule have been stated: (1) that the antenna must be a multiple of half wavelengths, and (2) that the antenna must be resonant. Now the easiest way of achieving this is to cut the wire to a resonant length. However, if this cannot be done, other ways are possible.

In the pages to follow, we will discuss ways of resonating antennas not naturally resonant in themselves, and we will point out ways of changing the antenna's electrical length. Before proceeding much further, however, the reader should become aware of a few basic antenna rules with which we must cheat a little.

- The higher in the air you can get it, the better.
- A naturally resonant antenna is more efficient than an artificially resonant antenna.
- An outdoor antenna is more efficient than an indoor antenna.
- An antenna inside a frame building is more efficient than an antenna inside a metal-reinforced building.

NOTE: Even if you have the lousiest possible antenna, as defined under these rules, you should get *some* results. Also, if you don't have a reflected power meter, *GET ONE!*

## QUARTER-WAVE ANTENNAS

When I put my first rig on the air I was living in a three-family house, and the largest open stretch, other than the street, was about 20 feet to the house behind mine. Luckily though, my shack was in the front, and conveniently in the attic. From the front of my roof to the middle of my neighbor's roof I found I could just squeeze in a 63-foot wire. In those days there was no 40-meter Novice band—just 80, 11, and 2 meters. I was pretty well stuck with 80. Fortunately I was in good with the people in back, and obtained their OK to anchor one end of the wire to their roof.

The antenna was fed as a quarter-wave line, using the same methods recommended for a ground plane. Of course there were no radials, just a wire going down to a ground rod. Nonetheless the antenna loaded up nicely. In fact, considering that I was using a home-brew, one-tube transmitter, and what must have been the last Armstrong regenerative set used by a ham other than a historical buff, the results were phenomenal. I even managed to get a public-service award from the ARRL for checking into a net during a hurricane. (I had my General by then.)

The point is, when living in an urban setting, a not-too-unresonable run of 65 feet allows you to put up a fairly efficient antenna for 80 meters. This antenna can be end-fed in the same way on 160.

A quarter-wave antenna can be made to match almost anything, aided by a series-tuned circuit. A 50-ohm source connects through the series-tuned circuit; any other line can be link-coupled into the series-tuned circuit, which is connected from the end of the antenna to ground. In fact, my first transmission line consisted of a twisted length of lamp cord! Of course I had no idea what the SWR was. In fact, I didn't even know there was such a thing. The antenna did, however, take power from the transmitter; my tube didn't overheat, and I did make some contacts with it.

Keep in mind, in an emergency you can load a wire with the circuit shown in Fig. 8-1A using almost any kind of transmission line, and obtain *some* results. Always remember, space problems are inversely proportional to how well you get along with your neighbors. Often, apartment dwellers can run a 65-foot line from their window to the roof and then horizontally across. Again, it depends on how well you're able to blend with your neighbors.

"Who, me? Oh no, I don't have a transmitter. I just have that wire up 'cause I like to listen to shortwave broadcasts!"

## INCREASING THE ELECTRICAL LENGTH OF A WIRE

*An antenna that is less than a multiple of quarter wavelengths long appears capacitive.* This is because it is no longer resonant, and the resulting phase relationship of voltage and current resembles a capacitive circuit. Now just suppose you have an antenna that isn't long enough cramped into your urban apartment or back yard. According to our rule, the wire offers a capacitive load for the transmitter. Why, then, can't you add an inductance to the antenna to balance that capacitive load thus making the antenna resonant? You can—and it works!

An undersize dipole can be made resonant by inserting an inductance into each half. Care should be taken to keep the two halves uniform with respect to one another. The system works better if the inductors are inserted a few feet from the ends,

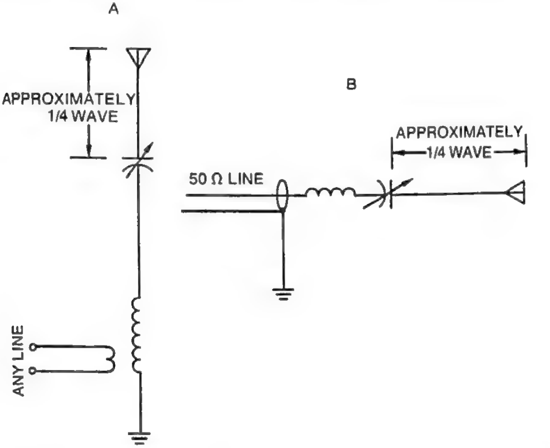



Fig. 8-1. Two methods of coupling into an off-resonant antenna. With the circuit at A, practically anything able to pass current can be used as transmission line. With circuit B, the cable should be 50 ohm. Both these circuits should be kept in mind for when an antenna must be thrown up quickly during an emergency.

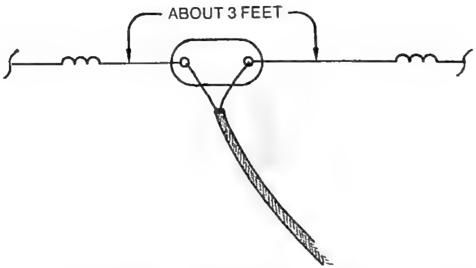



Fig. 8-2. A restricted-space dipole using inductive loading. The antenna should be symmetrical, with the coils inserted about two or three feet from the insulator. The more antenna length made up for by the coils, the sharper the tuning of the antenna. That is, it will have a higher Q, thus less bandwidth.

rather than at the ends. It is more frequency-sensitive than a regular dipole, but it will get you onto the low bands, using a minimum of space.

Formulas to determine the required inductance are more trouble than they are worth because they include unpredictable factors such as capacity to ground. It is much easier to measure the resonant frequency with a dip wavemeter, as outlined in Chapter 5, then "prune" the antenna by varying the inductances. Always be sure to make identical variations on each half of the dipole. It takes a while, but the end result is worth it. These inductance-lengthened antennas will be discussed further along, with the mobile antennas.

## SQUEEZING A HALF WAVELENGTH OF WIRE INTO A FEW FEET

A certain little suburb near Rochester, N. Y., (not the author's QTH) takes a rather spiteful attitude toward radio amateurs. Masts for TV antennas, CB antennas, and other purposes, need no permit of any kind. Antenna structures for amateur radio stations however, require a special permit before they can be erected. Then they are subjected to numerous restrictions, including a requirement that they be removed if any neighbor objects to the structures. One amateur there has gotten around it nicely.

Beginning with a length of 1 1/2-inch diameter PVC pipe, he wound 125 feet of wire around it, carefully spacing the wire to occupy the entire length. Next he coated the whole assembly with fiberglass, thus weatherproofing it as well as concealing the wire. After attaching a shiny metal ball and a small pulley to the one end, this amateur mounted it on his house, and proceeded to load it as a quarter-wave vertical on 80. The town? They're none the wiser, for every day this wise guy makes use of that pulley to fly an American flag from his antenna! The arrangement is shown in Fig. 8-3.

It's one of those funny things, that when you spiral-wind a half wavelength of wire, it acts like a quarter wavelength. The design is known as a helical antenna. The overall length at the spiral can be as short as 15 or 20 feet and still work. It is well

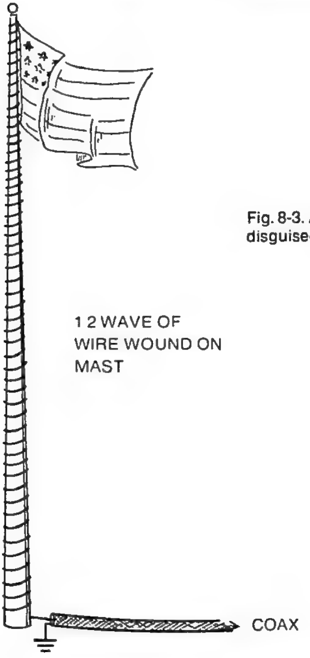



Fig. 8-3. A helical, vertical antenna disguised as a flagpole.

to mount a metal ball, disc, or other object at the top to prevent high-voltage corona (an American eagle maybe?).

You may find it necessary to use some form of coupler to get the best possible SWR. A series-tuned circuit should work for single-band operation. I've not tried it myself, but some amateurs use an L- or Pi-network for multiband operation. At any rate, concealed or not, a helix provides a nice quarter-wave vertical when you've nothing to fasten the distant end of other type antennas to.

## LOOP ANTENNAS

A loop antenna can be described as a magnetic dipole. That is, it responds chiefly to the magnetic field component of a signal whereas a conventional dipole responds chiefly to the electric field component. This magnetic-field, rather than electric-field response makes it unique in that it is relatively insensitive to lightning static and many forms of man-made noise. While loops have long been applied as direction finders and used in AM broadcast receivers of the forties and fifties, for no logical reason, they seldom have been applied as transmitting antennas. This, in spite of the fact that, as one engineer put it, "They are damned efficient radiators."

Two classes of loops exist, small and large, the distinction being the length of wire relative to a wavelength, rather than the physical dimensions. A small loop at one frequency can be a large loop at another.

A small loop is one in which the amount of wire is less than a half wavelength. Current distribution throughout the loop is constant in direction and magnitude. It is, in fact, a large coil. It is directional in the plane of the loop, with no radiation at right angles to the plane. Polarization is at right angles to the plane of the loop. Finally, like a coil, a small loop can be resonated.

A large loop is one in which the length of the wire is more than a half wavelength. Current distribution is uneven and reverses direction at half-wave intervals. This does weird things, such as presenting directional characteristics opposite to those of small loops.

A single-turn loop that is exactly one-half wavelength along its perimeter has characteristics resembling both small and large loops. Although the current travels in only one direction throughout the entire loop, magnitude varies, with

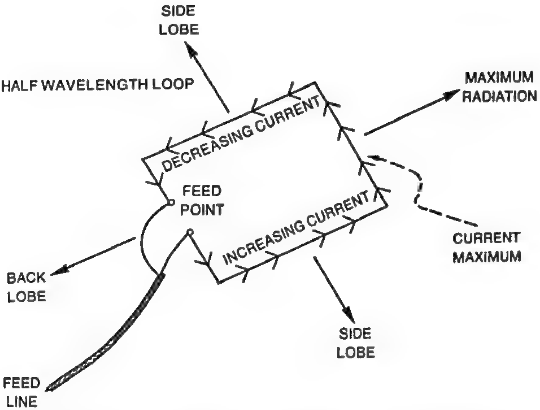



Fig. 8-4. Current distribution and radiation in a half wavelength loop. Radiation is in the plane of the loop, with relative intensities indicated by the length of the arrows.

maximum current at the exact midpoint of the wire. Since the current at the feed point is minimum (being 90° away from the current maximum), the feed-point impedance is in the order of several thousand ohms. Directivity is maximum in a direction from current minimum to current maximum. Front-to-back ratio is relatively low, about 2:1, at the most. Also, some radiation takes place at right angles to the plane of the loop. These characteristics appear in Fig. 8-4.

Opening the midpoint of a single-turn, half-wave loop (Fig. 8-5) places the current minimum quite naturally, at the open point. This reverses the directional characteristics and puts the low impedance at the feed point, where it is wanted.

As previously mentioned, a loop that is a full wavelength along its perimeter radiates at right angles to its plane (Fig. 8-6). Polarization of a vertically positioned loop is horizontal when the loop is fed at the bottom and vertical when the loop is fed at one side. Radiation resistance is in the order of 100 ohms, making it relatively easy to match. These loop configurations shorten the electrical length of the wire to the extent that the wire must be cut 7% longer. A full-wavelength loop finds use primarily as an element in a quad antenna,

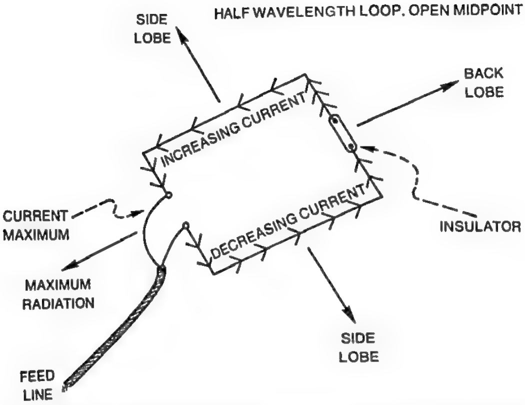



Fig. 8-5. A half wavelength loop with the midpoint an open circuit. This puts the current maximum, and maximum radiation, at the feed point.

which will be covered with directional arrays. Figure 8-7 shows a makeshift loop salvaged from a wind damaged quad antenna.

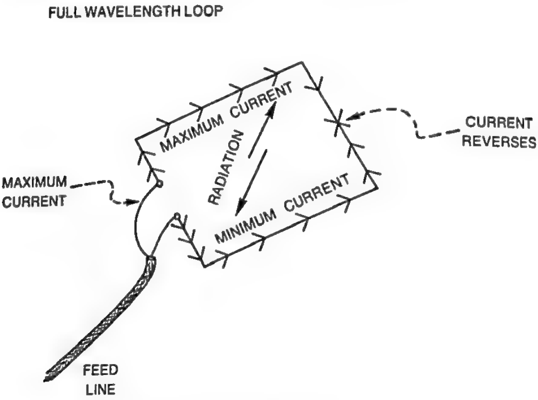



Fig. 8-6. A full wavelength loop has a current reversal at the midpoint. Radiation is broadside to the plane of the loop.

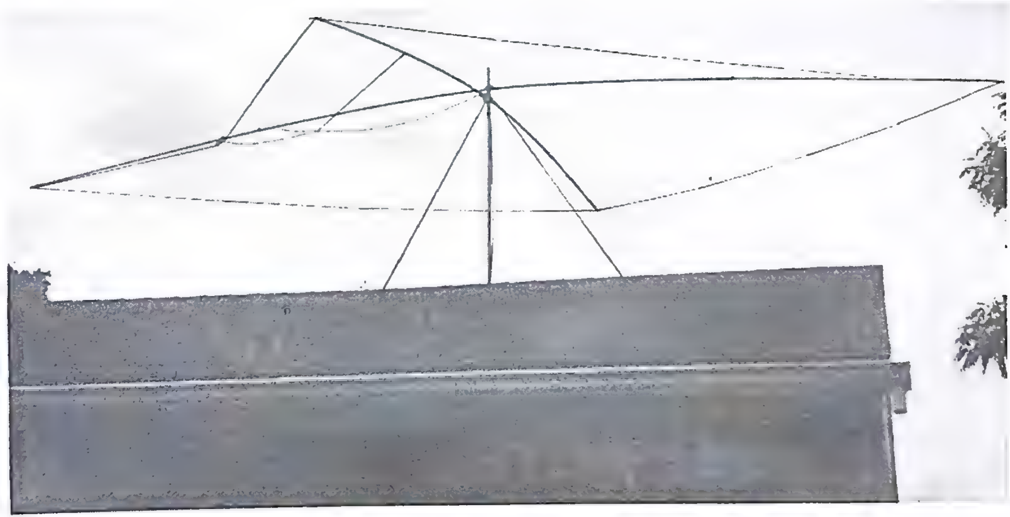


Fig. 8-7. When this fellow's quad came down in a winter storm, he simply re-mounted the 20 meter driven element as a horizontal loop and operated successfully with it for over a year. His SWR was a bit high, but he could have compensated for this with a tuner.

**Super Loop**

All the information about loops in the preceding paragraphs may be of some use to the technically oriented amateur, but the amateur who is not intimately involved in electronics is still left hanging. "So what? How can I use these principles to make a nice, small antenna that can be kept on the roof or in my room, yet will really get out?" Finding an answer to this question wasn't easy. Very little has been written about loops. In the course of trying to find an answer, though I stumbled upon the Super Loop.

This antenna, although made from a half-wavelength wire consists of three turns. This establishes the current loop (peak) opposite the current node, cancelling out the directivity. The total perimeter, being that of a small loop, makes the antenna show some of the desirable characteristics of a small loop: it can be tuned to resonance, it is relatively insensitive to static, and it accepts a wide range of frequencies. Radiation area of a small loop is equal to the area enclosed, multiplied by the number of turns in the loop. Consequently, it squeezes 420 square feet of radiation area into an average size room.

The loop is mounted vertically and radiates a horizontally polarized wave. With very little radiation straight up, the radiation angle is fairly low. A test loop was made with 130 feet of ordinary bell wire stapled to the wall, near the ceiling, in a 10- by 14-foot room. See Fig. 8-8. The three turns were spaced about two inches apart. It was fed through an L-network consisting of a 7-microhenry inductor and a 250-pF capacitor. After tuning for minimum SWR on 80 meters, the ratio was less than 1.1:1 throughout the entire band without readjusting the capacitor. Transmissions made from this antenna, using a 180-watt transmitter, brought highly favorable reports from stations 500 to 1000 miles away.

If your operating location is in a room comparable to the $10 \times 14$ room just mentioned, three turns of wire tacked to the wall near the ceiling will do. For larger rooms, I recommend suspending some sort of support near the ceiling to hold it. Some tolerance exists in the total length of wire used—the L-network compensating for variations. Of course, there is nothing wrong with supporting the loop over your yard or on the roof.

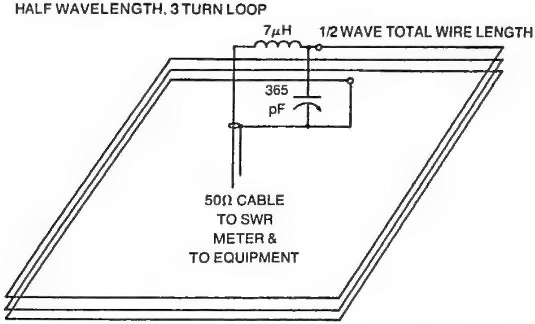


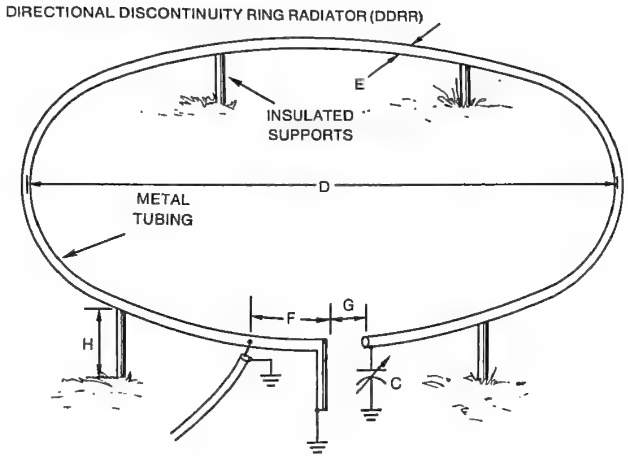

Fig. 8-8. A three-turn loop with an L-network coupler is an ideal 80-meter indoor antenna. It can be mounted to a wall or other vertical support. Increase the inductance to 10 $\mu$H for a two-turn loop, or to 27 $\mu$H for a one-turn loop, using 125 feet total length of wire.

Mount the coupler components right at the feed point. It may be necessary to vary the amount of inductance in the L-network slightly to compensate for location variations, but not more than a turn or so either way. For a 40-meter loop, try halving both the wire length, and the values of L and C in the coupler.

To tune the Super Loop, set your transmitter, at reduced output, to midband. Tune the transmitter for maximum forward power, then adjust the capacitor on the Super Loop for minimum SWR. This should occur with the plates almost fully meshed. After that, the coupler need not be retuned for variations within the band.

## DIRECTIONAL DISCONTINUITY RING RADIATOR (DDRR) (TRANSMITTING WITH THE GARDEN FENCE)

This unique antenna design was designed and patented by J.M. Boyer, W6UYH, in 1962. It was first written up in *Electronics* magazine in January, 1963. It consists of a conductor, approximately a quarter-wave long, grounded and arranged in a circular configuration. Some question exists as to why it works, but it nonetheless works almost as well as a quarter-wave tower. Such an antenna, for the 80-meter band, could fit in an average size back yard. In communities where




| | |
|---|---|
| C | 160—150 pF<br>80—100pF<br>40—75pF<br>20—50pF<br>15—25pF<br>CB—15pF<br>10—15pF<br>6—10pF<br>2—5pF |
| D FEET | $\frac{407.2}{2\pi F_{MHZ}}$ |
| E | APPROX. 3/G<br>USE NEAREST STANDARD SIZE |
| F | APPROX 4/H<br>ADJUST FOR BEST MATCH |
| G FEET | $\frac{H}{3}$ |
| H FEET | $\frac{D}{9}$ |

Fig. 8-9. A DDRR antenna. The diameter for an 80-meter antenna would be about 18 feet. Ground radials should be buried beneath the antenna for maximum efficiency.

the neighbors might fuss about amateur radio operation, it could easily be made to look like a circular garden fence, but woe to anyone who tries to climb over and steal your tomatoes while you're transmitting.

The DDRR operates as a resonant section of transmission line (with the surface of the ground serving as the other conductor). If it were stretched out straight, little or no radiation would result. However, each time the direction is changed, an unbalance results that produces radiation. The circular configuration is a constant discontinuity of direction, hence the name Directional Discontinuity Ring Radiator.

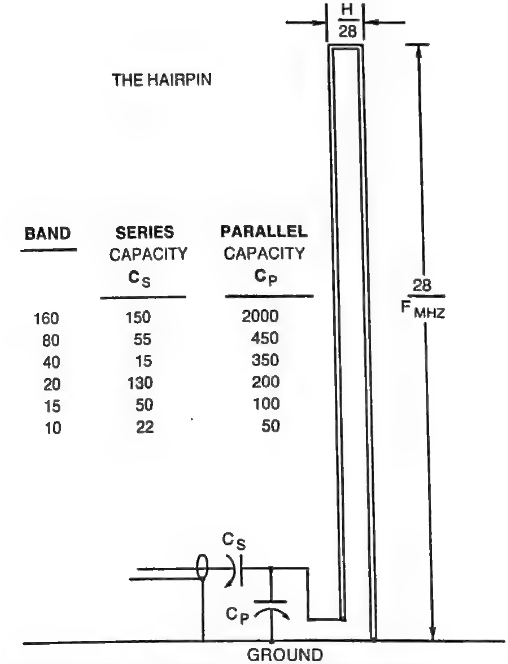
A DDRR antenna as shown in Fig. 8-9, is constructed of metal tubing, the diameter depending on the frequency to be used. Supports are generally upright pieces of plastic pipe or other suitable insulating material. A good ground is essential, buried wire radials being recommended. It is relatively narrow in bandwidth, the end capacitor requiring adjustment for frequency changes of more than 20 or 40 kHz. Some solve this problem by controlling the capacitor remotely, either with a servo motor or a string-and-pulley arrangement.

A DDRR antenna is, for all practical purposes, omnidirectional. Its efficiency as a radiator seems to be somewhat less than that of a quarter-wave tower. For the higher frequency bands, it can be built small enough to fit neatly, almost ornamentally, on a car roof. With careful trial-and-error selection of the feed point, SWR approaching unity can be achieved.

## THE HAIRPIN

This antenna was developed by General Dynamics. It consists of two parallel, vertical conductors, shorted at the top, having one conductor grounded at the bottom, while the other one is driven there. It is approximately 14 electrical degrees long and is tuned with two capacitors. The prototype General Dynamics built was 14 feet long and was operated all the way from 2 to 30 MHz. SWR as low as 1.3 was claimed.

A hairpin antenna illustrated in Fig. 8-10, can easily be constructed from copper tubing and plumbing fixtures. Spacing between the two conductors was not given, but a photograph of the device indicated it to be about six inches. The chart included with the figure gives capacitor values for the various amateur bands, when used with a 14-foot radiator.




| BAND | SERIES CAPACITY $C_S$ | PARALLEL CAPACITY $C_P$ |
|---|---|---|
| 160 | 150 | 2000 |
| 80 | 55 | 450 |
| 40 | 15 | 350 |
| 20 | 130 | 200 |
| 15 | 50 | 100 |
| 10 | 22 | 50 |

Fig. 8-10. The Hairpin antenna. Note the similiarity between this and the antenna shown in Fig. 9-3.

They are estimated values based on published data. Precise values can be determined by trial and error using these values as starting points. For lower power than the 10 kW used by General Dynamics, smaller conductors can be used. Also, for any given band, the antenna should be made about 14 electrical degrees long. This would be less than seven feet at 80 meters. As with other restricted-space antennas, a good ground is essential.

## RANDOM LENGTH WIRE

Any random length of wire can be loaded, with varying degrees of efficiency, if a good pi-network coupler is available.

Quite understandably, radiation efficiency is less than may be expected from a resonant antenna. To tune simply adjust for maximum forward power, then fine-tune by dipping the SWR. Of course, with random-length antennas, some experimentation with the inductance may be required to obtain a suitable match. Some lengths of wire may have an impedance within the range of the output network of your transmitter, in which case no coupler would be required.

Also, a length of wire having a high impedance on one band might have a low impedance on another band thereby requiring a series-tuned circuit instead of an L- or Pi-network.

The importance of a good ground cannot be overemphasized. With random-wire antennas, you may find that

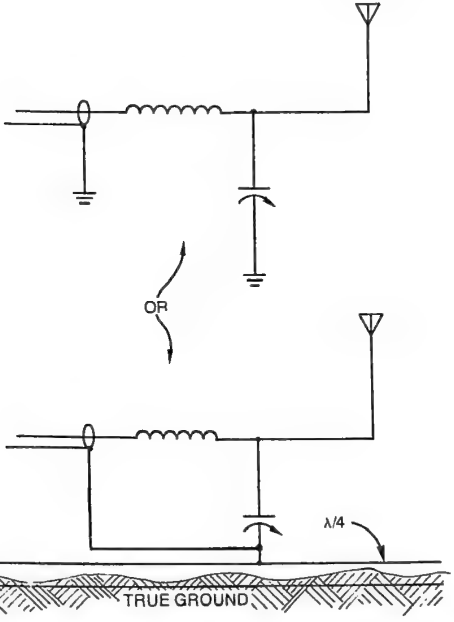



Fig. 8-11. Where necessary, ground can be simulated by suspending a quarter wavelength of wire a few feet above true ground.

one ground system works better than another. Where obtaining a good earth ground connection is impractical, a counterpoise consisting of a quarter wave of wire supported a few feet above the ground will provide a good substitute (Fig. 8-11).

## TOP LOADING

Sometimes a half or a quarter wavelength can be combined in a vertical and horizontal configuration. In such a case, if the length indicated by dimension X in Fig. 8-12 is either a half or a quarter wavelength, you can match it to your

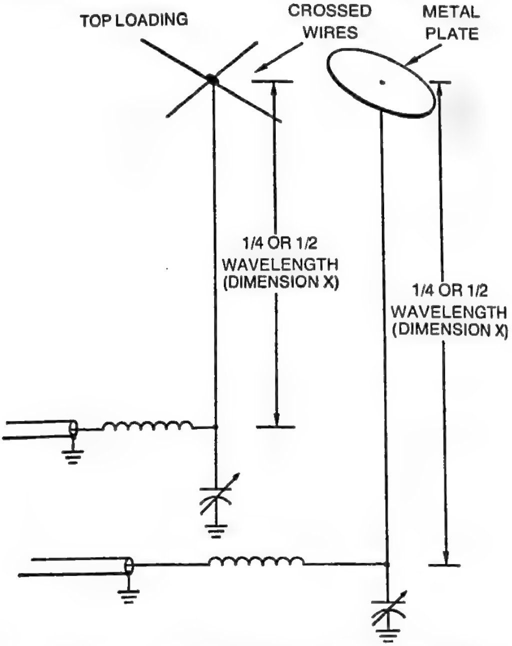



Fig. 8-12. The crossed wires and metal plate provide capacitance to resonate with the inductance of the vertical wire. If dimension X is a half wavelength, the matching L network must be provided. For quarter wavelength vertical wires, the coax can be coupled directly to the radiator.

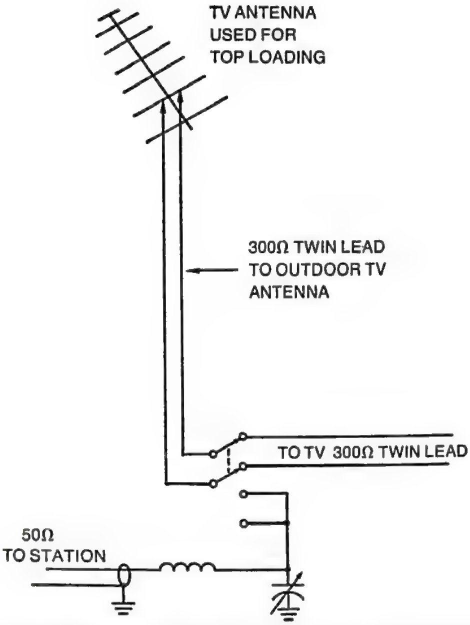



Fig. 8-13. A DPDT switch and a matching network converts an outdoor TV antenna installation into a top loaded, random wire amateur antenna.

transmitter, directly if a quarter wavelength or through an L-network if a half wavelength.

In these cases, the top section is actually forming a capacitor to resonate with the inductance of the wire. More capacity provides better results. Additional capacitance for vertical wires can be obtained by using two lengths of wire at the top arranged in a cross. If there is no room for stringing wire, a large area of metal can often substitute.

More than one ham has loaded his TV antenna system by shorting the two conductors of the twinlead together and using it as a single conductor. In such cases, the TV antenna elements serve as a capactive, top-loading antenna element (Fig. 8-13).

# Chapter 9
# Mobile Antennas

Mobile operation, especially on the lower amateur bands, involves the ultimate in restricted-space antenna systems, and a good deal more. Unlike fixed station antennas, a mobile antenna must work against a very small, irregularly shaped ground plane. Usually, no two antennas mount at the exact same point on their respective car bodies, and most times they will be on differently shaped vehicles. Consequently, it is only in rare cases that two mobile antennas give optimum performance under identical tuning and matching conditions.

Mechanically, a mobile antenna must be strong in construction, light in weight, and small in profile. It must be capable of withstanding the constant vibration stress accompanying normal driving; it must be able to withstand prolonged winds, often in excess of 80 m.p.h. (with a head wind) that result from normal driving conditions. Finally, it must be small and light enough to be carried on the vehicle without being ungainly, or subject to damage caused by the whipping effects of normal maneuvering of the vehicle.

A whip is the only antenna that even comes close to meeting all those requirements. Now the amateur operating on, say, 75 meters would find a 65-foot whip a bit ungainly on his Volkswagen, so he uses a much shorter whip and adds an inductance to electrically lengthen it.

## LOADING COILS

This brings up three classes of amateurs who operate mobile: those who put their loading coil at the bottom, those

who put it in the center, and those who put it at the top (see Fig. 9-1). No matter which method I might say is superior, I surely would hurt somebody else's feelings. Each position has its advantages and its disadvantages. Bottom loading is best mechanically, but it produces a very low radiation resistance, and since most of the radiation is from the loading coil, some believe it to be a relatively inefficient radiator.

If the inductor is moved up on the whip, radiation resistance increases but more inductance is needed for resonance. Antennas with the loading coil at the top are very rare because the heavy inductor would make an unwieldy assembly. In fact, I haven't seen a top-loaded whip for many years.

Center-loaded whips offer, what many call, a good compromise. Although the radiation resistance is still quite low (less than 1 ohm at 75 and 160 meters), current distribution along the whip is more uniform than with bottom

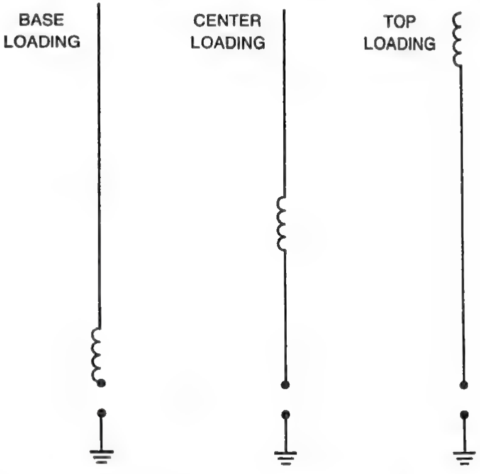



Fig. 9-1. Three methods of loading a mobile whip. Only base and center loading are commonly used. Top loading, because of its weight and wind resistance, rarely is seen. Base loading works well for antennas mounted on the roof of the vehicle; center loading performs well with antennas mounted to a fender or bumper.

Table 9-1. Bottom Loaded Whip Characteristics.

| Length (feet) | 1/8 inch diameter (pF) | 1/4 inch diameter (pF) | 1/2 inch diameter (pF) |
|---|---|---|---|
| 6 | 17 | 19 | 22 |
| 7 | 19 | 22 | 25 |
| 8 | 22 | 24 | 27 |
| 9 | 24 | 27 | 30 |
| 10 | 26 | 30 | 33 |
| 11 | 29 | 32 | 36 |
| 12 | 31 | 34.5 | 39 |

loading. The coil is larger than with bottom loading, but is still manageable, and tuning, while difficult, is a bit easier with a center-loaded whip.

Some amateurs use a helical antenna, which seems to work out well on 20, 15, and 10 meters. Such an antenna is however, is restricted to single-band operation by its very nature and is quite frequency sensitive as are all mobile antennas. Otherwise the helical works quite well. These antennas were more fully described in the preceding chapter.

For VHF operation the problem is greatly simplified, hence the popularity of 6- and 2-meter mobile operation. Antennas for these bands are small enough so that an entire quarter wavelength or even the popular 5/8 wave whip fits onto the car. Directional loops are sometimes used on 10, 6, and 2 meters but whips are by far the more common.

## LOADED WHIPS

An antenna that is less than a multiple of a quarter wavelength long appears capacitive. Just how much capacity it represents depends on its exact length in electrical degrees, which in turn is governed by the velocity factor of the conductor; it also depends on the mass of the conductor, its position with respect to ground, and the shape and conductivity of the ground. Table 9-1 gives approximate capacitance values for bottom loaded whips of various diameters and lengths. For tapered whips, use the average diameter.

Use these values as ball park figures for determining the coil inductance required to resonate a whip to the operating frequency. Making a whip resonant by inserting an inductance to tune out the capacity, in effect, increases its electrical

length. For a bottom loaded whip, use the capacity given in the table; for a center loaded whip, use half that amount.

**Calculating Whip Capacitance**

For antenna lengths not included in the table, or for individual designs, the capacity represented by a base loaded antenna can be roughly calculated from the following formula. For center loaded antennas, use half the calculated capacitance.

$$C = \frac{17L}{[\log_n(D/24L) - 1][1 - (234/fL)^3]}$$

C is the capacity in micro farads
L is the antenna height in feet.
D is the diameter in inches.
$\log_n$ is the *natural* log, and is roughly $2.3 \times \log_{10}$

Once the capacity is known, the next step is to find the inductance to resonate at the desired frequency. This can be calculated from the formula given in Chapter 1. Remember, if the whip is to be center loaded, use half the capacitance determined in the above formula.

For the lower amateur bands, values to resonate and match an 8-foot whip to a 50-ohm transmitter output are given in Table 9-2.

**Table 9-2. Loading and Matching an 8-Foot Whip.**

| | | Capacitive Matched | | Inductive Matched | | |
|---|---|---|---|---|---|---|
| **Frequency MHz** | **Feed-Point Resistance** | **Loading Inductance** | **Matching Capacity** | **Loading Inductance** | **Matching Coil** | |
| 1.8 | 23Ω | 292 µh | 002µF | 287µH | 4µH | BASE LOADED |
| 3.9 | 16Ω | 63µH | 0012µF | 61µH | 1.4µH | |
| 7.2 | 15Ω | 19µH | 680pF | 18µH | 0.72µH | |
| 14.2 | 12Ω | 4.89µH | 400pF | 4.41µH | 0.31µH | |
| 21.2 | 16Ω | 1.776µH | 220pF | 1.424µH | 0.26µH | |
| 1.8 | 34Ω | 581µH | 0012µF | 577µH | 2.06µH | CENTER LOADED |
| 3.9 | 22Ω | 124.4µH | 920pF | 122.5µH | 1.8µH | |
| 7.2 | 19Ω | 36.7µH | 565pF | 35.6µH | 0.87µH | |
| 14.2 | 19Ω | 9.57µH | 286pF | 9.0µH | 0.44µH | |
| 21.2 | 27Ω | 4.39µH | 140pF | 4.01µH | 0.41µH | |

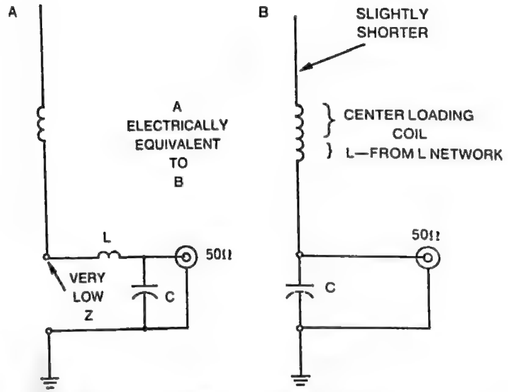



Fig. 9-2. Evolution of capacitive impedance matching. Because a short whip has a much lower impedance than a transmitter, the L-network matching circuit must have the inductor toward the antenna. This allows us to combine it with the antenna loading coil, where it becomes part of the effective radiation.

## Matching A Whip

Most whips, whether base loaded or center loaded, have a telescoping top section to allow for adjustment of length. To make this adjustment, have the whip and loading coil mounted in place, then couple a dip wavemeter into the whip through a loop of wire connected across the feed point. The transmission line should not be in the circuit. Set the dip wavemeter to the desired frequency and adjust the length of the telescoping section for an indication on the dip wavemeter.

To match the transmitter to the antenna impedance, you need a reflected power meter. There are three methods of matching the very-low, feed-point resistance of a whip to the 50-ohm output of a transmitter.

**Shunt Capacitor.** We can start with an L network. Note that, since the transmitter output is now a higher impedance than the antenna impedance, the L network is connected opposite to the methods shown in Chapter 4. Thus the inductance of the L network can now be combined with the loading coil inductance where it will help radiate. This evolves into the first method of matching impedance—with a shunt capacitor (Fig. 9-2).

**Tapped Inductor.**

Imagine a quarter-wave vertical antenna connected to the ground. Fig. 9-3A. The impedance of this antenna is near zero at the grounded end and approaches infinity at the top end. Somewhere along its length a point exists where the impedance is 50 ohms, and the antenna can be fed at that point.

Now consider a mobile whip as a short wire that has been electrically lengthened (Fig. 9-3B). If part of the inductance that electrically lengthens it is moved to the bottom, a point can be found in that inductance where the impedance is 50 ohms, and a transmitter can be tapped into it (Fig. 9-3C). This is the second method of matching impedance—with a tapped inductor.

**Shunt Inductor.** Once the 50-ohm point is found in the inductor, the remaining inductance can be moved back to the loading coil, giving the third method of matching impedance—with a shunt inductance (Fig. 9-3D). All of these methods work, and each one has its following in the amateur world. No matter which method you choose, though, tuning will be very critical, but once it's nailed down, results should be extremely satisfying.

## MOBILE ANTENNA CONSTRUCTION

The mechanicals requirement of mobile antennas make commercially built models out-and-away more popular than home-brew versions. Building a mobile antenna, though, is not impossible by any means. But, it is best, unless you're a capable machinist, to buy the mount. Other antenna elements can be built or improvised as necessary. So long as the final product fulfills the rules (the correct length of good conductor and the proper amount of inductive and/or capacitive reactance) it will work. The antenna shown in Fig. 9-4 produces good, solid copy with stations several hundred miles away, and when conditions are ideal, gets out much farther.

Antenna mounts are available for either body or bumper mounting; I chose body mounting simply because I preferred it—for no other reason. You will notice that the bottom portion of the antenna is mounted rigidly to the car body. Since this lower portion offers the greatest amount of capacity with respect to the car body, changes caused by swaying of the antenna would thereby have the greatest effect in this section.

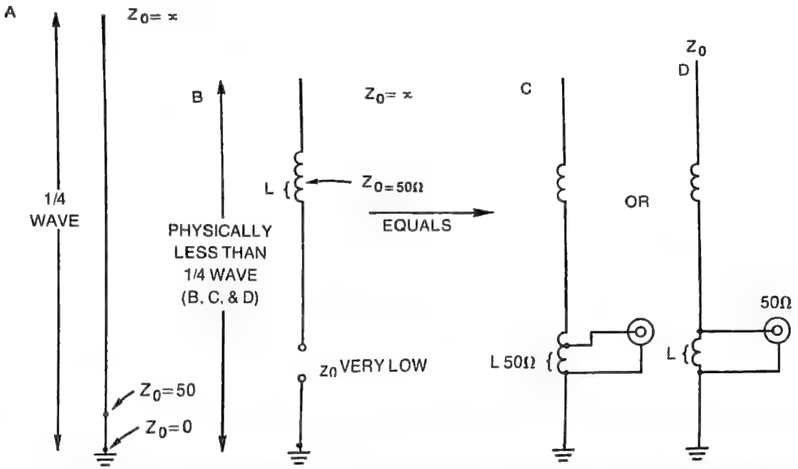



Fig. 9-3. Evolution of Inductive Matching. At A, the 50-ohm point is shown on a grounded, quarter-wavelength vertical wire. At B, the wire is physically less than a quarter-wavelength, but has been made electrically equivalent to a quarter-wavelength antenna by the addition of an inductor. A very low impedance appears near the base, which is not suitable for matching amateur transmitters and receivers. At C, part of the loading coil has been inserted at the base, then tapped at the 50-ohm point. At D, the turns not required to obtain 50 ohms have been placed back into the midpoint loading coil.

Making this section rigid seemed the best way to go. Commercially made antennas do not, so far as I know, do this.

This bottom section was made of 3/8 inch steel rod, threaded on either end. The upper end was cut with threads to move with the antenna mount; the lower end was cut with standard 1/8-inch pipe threads (1/8 inch pipe has an outside diameter of 3/8 inch). To improve conductivity, a piece of 3/8 inch copper tubing was slipped over the steel rod.

For the loading coil, a 14-inch length of 1 1/4-inch PVC pipe was closewound with #14 enameled wire through 12 inches, providing just the right amount of inductance for 75-meter

Fig. 9-4. A home-brew mobile antenna. While nowhere as neat as its commercial cousin, this collection of parts performs admirably.

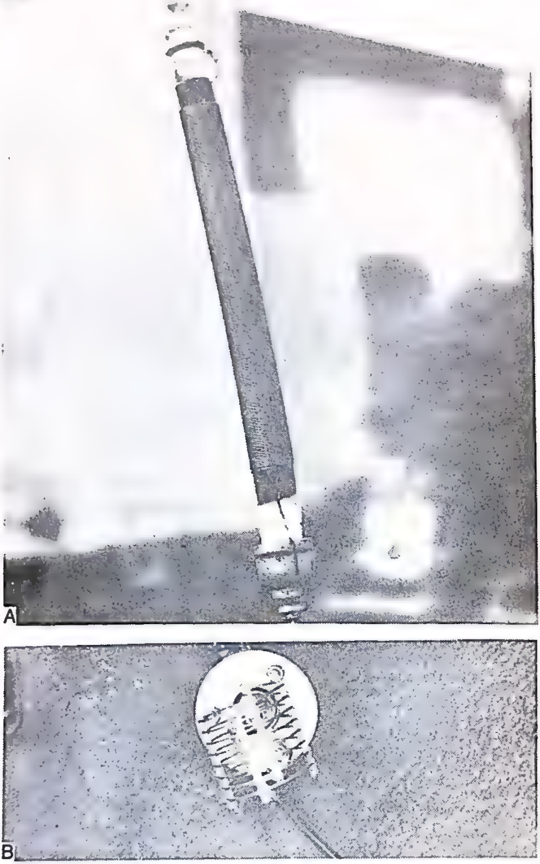



Fig. 9-5. Loading and matching coils for the home brew whip. The loading coil (A) is wound on a length of PVC pipe, then fastened to the bottom section with common plumbing fixtures. Mounted to the top is a conventional, telescoping whip. At B, the matching coil is shown mounted inside the fender.

operation. It mounts to the bottom section of the antenna through use of a series of reducers and bushings adapting from the 1 1/4-inch PVC pipe to the 1/8-inch thread on top of the steel rod (Fig. 9-5A).

Mounted to the top of the loading coil is a telescoping auto antenna found on the Get-Rid-of-it-Quick counter at a local Radio Shack. Being spring loaded makes this top section quite handy when I want to change frequency. It was mounted by drilling a hole and securing with a single mounting nut. I mounted it on a "dead-end" cap for 3/4-inch PVC pipe and cemented a 12-inch section of pipe to the cap. This pipe fits into the larger pipe used for a coil form, thus securely mounting the upper section of antenna. Wires from the coil were soldered directly to the copper tubing on the bottom section and to a large lug on the top section.

Matching impedance to the antenna required that a 1 3/4-inch section of B&W #3021 inductor be connected directly across the feed point inside the trunk (Fig. 9-5B). After a brief tune-up procedure, I was in operation, having spent less than $10 on my entire antenna system. Some other antenna arrangements are shown in Fig. 9-6.

Table 9-2 is provided for the benefit of those having the spinach to build a mobile-antenna system from scratch. Values are given for either capacitive or inductive matching of impedance. No values are provided for CB or 10-meter operation, since an 8-foot antenna (without a loading coil) is naturally resonant at 10 meters, and when made 6 inches longer is naturally resonant at CB frequencies.

Mobile antennas are, characteristically, very fussy frequency-wise. The lower the frequency band, the more critical the tuning, and the narrower the bandwidth. On 75 meters, for example, a bandwidth of 10- to 20-kHz is typical. Once the initial tune-up is completed, however, changes in frequency can be performed simply by making slight changes to the length of the telescoping section. *A step-by-step initial tune-up procedure is given in Chapter 5.*

## LOOPS

Loop antennas have little or no application in the present state of mobile operation, although, on a few occasions, they appear in "hidden-transmitter hunts" and in other unique applications. A commercially made 6-meter loop is available

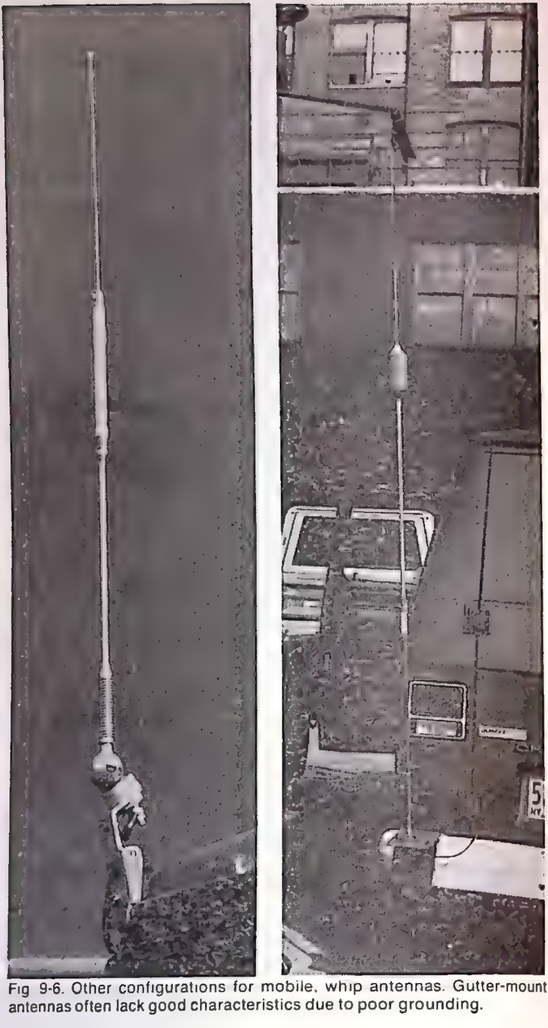


Fig 9-6. Other configurations for mobile, whip antennas. Gutter-mount antennas often lack good characteristics due to poor grounding.

which mounts a few inches above the car roof. On lower frequencies it seems that a horizontal loop is rendered ineffective by the car body.

Vertical loops used in mobile operations fit the category of small loops. They are simply large-diameter inductors, resonated with a capacitor, and are used more for directional receiving than for transmitting. Since loops are magnetic-sensitive devices, they are less responsive to the electrical field characteristic of static, either natural or man-made. Furthermore, a loop can be electrostatically shielded without lessening its effectiveness as an antenna (Fig. 9-7).

**Citizen Band**

Three types of mobile antennas are generally used for CB operation. These are quarter-wave whips, helical antennas, and loaded whips. A quarter-wave whip at CB frequencies is approximately 8 1/2 feet long, and fits on the rear bumper of the average car without too much inconvenience. Home-brew

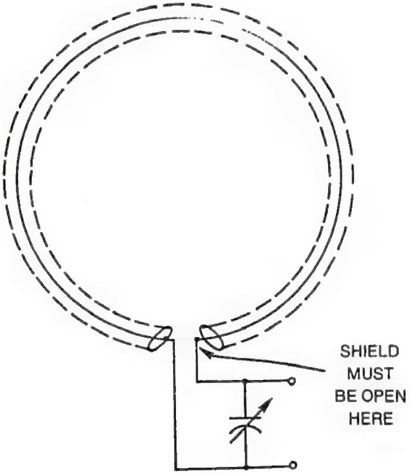



Fig. 9-7. A shielded loop antenna. Because a loop responds to magnetic fields, it can be electrostatically shielded without loosing effectiveness as an antenna.

whips should be pruned by a competent person with a good reflected-power meter.

Those not liking the size of a quarter-wave whip may use a helical antenna. This consists of a half wavelength of wire wound into a long, narrow coil. In this form it has characteristics similar to a quarter-wave whip, and is small enough to be mounted on the roof of the car, where the most efficient operation can be realized.

The most popular of the three types, the loaded whip, is also the least efficient. This type of antenna, often mounted simply by clamping it onto the gutter at the edge of the car roof, works by exactly the same principle as the low-band amateur mobile antennas previously described. Since a loaded whip has a comparatively low radiation resistance, much of the transmitting power is wasted in the resistance of the whip and loading coil. It is, nonetheless, very popular because of its small size and ease of installation. CB operators attempting to home-brew this type of antenna should be aware that the tuning is very critical, and will require many of the instruments described in this book—and a lot of patience.

**VHF Amateur**

Eight-foot whips are naturally resonant, as a quarter wave antenna, to the 10-meter amateur band, requiring little or no pruning. At 6 meters, a 4 1/2-foot whip is a natural quarter wave.

As previously mentioned, antennas slightly longer than quarter-wavelength multiples appear inductive, while antennas slightly shorter than quarter-wavelength multiples appear capacitive. Midway between a quarter- and a half-wavelength the antenna appears neither inductive nor capacitive. Also, it is nonresonant. If such an antenna can be impedance matched to the transmitter, it would show a wide frequency tolerance. Moreover, under these conditions, the antenna impedance matches the radiation resistance of the air around it. Remember from theory that maximum power transfer occurs between equal impedances. Under these conditions, the radiation efficiency of the antenna is at its maximum and the antenna actually shows some gain over a dipole. This is the principle of the extremely popular 5/8-wave whip (Fig. 9-8). A matching network must be used to couple the antenna to the transmitter, however.

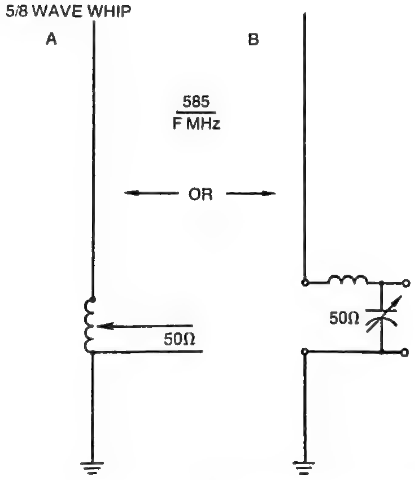



Fig. 9-8. The 5/8-wave ship becomes practical for 6- and 2-meter mobile operation. Its nonresonant, wide-band characteristic makes it attractive on the broad VHF bands.

On two meters, quarter-wave whips either with or without a set of ground-plane radials find extensive use, and are nicely sized to mount in the center of a car roof. On the other hand, 5/8-wave whips usually mount on the trunk lid. Hand-held walkie-talkies often use a quarter wave helix made of springy material jacketed with a thin rubber cover. This makes a very small, quite efficient antenna. It is nicknamed the "rubber ducky".

A large number of other antenna configurations are used by the two-meter FM enthusiasts. Since nearly every type of nondirectional, two-meter antenna can be mounted easily on a vehicle, discussion of these will be saved for the chapter on VHF antennas.

# Chapter 10

# Long Wires and Directive Arrays

We often hear the term "long wire" applied to almost any antenna for the lower amateur bands, particularly when the antenna is end-fed. In strictly technical terms, however, a long wire is long only with relationship to the wavelength being transmitted or received. Specifically, a long wire is two or more wavelengths long.

Such antennas have both advantages and disadvantages, space requirements being the biggest disadvantage. The greatest advantages are directivity and gain with respect to a dipole, and wide frequency tolerance. Generally speaking, the greater the number of wavelengths long, the broader the bandwidth. There is, of course, a practical limit beyond which the disadvantage of large size outweighs the increased bandwidth.

Now, as to directivity, either a long wire or a directive array certainly has a much poorer gain or directivity-versus-space ratio than a beam. However, there are times when a beam may not be the most desirable. Beams, as we all know, are unidirectional, and have so narrow a coverage that they are generally useable only for point-to-point communications. Directive arrays are usually bidirectional, and long wires quadradirectional. If carefully oriented, they can simultaneously cover several desirable regions. Their coverage spreads wider than a beam, giving area, rather than point-to-point communication.

## LONG-WIRE PATTERNS

The directivity of a long wire can be better understood if we analyze it as though it were a combination of half-wave antennas—an oversimplification, perhaps, but it allows us to form a fairly clear picture of what we're doing. First of all, let us recall from Chapter 2 that a half-wave antenna radiates or receives primarily broadside to the wire. If the radiation could be made visible, it would form a doughnut shape around the wire. A cross section of the pattern would look like Fig. 10-1.

The dashed line represents the current at a given instant. The positive and negative signs are only meant to indicate the relative direction of the electric field from one side to the other. Now, if we put two half-wave antennas end-to-end, they would each try to radiate the pattern of half-wave antenna

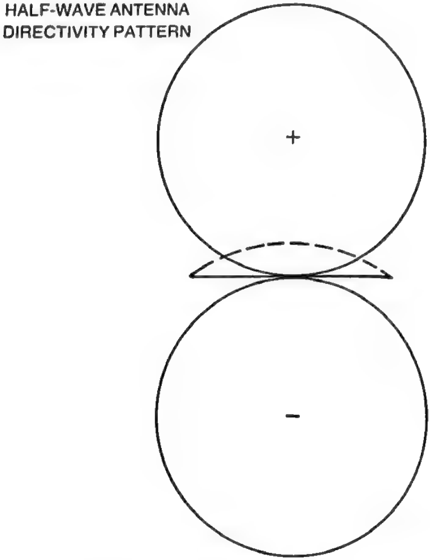



Fig. 10-1 Current distribution and radiation pattern on a half-wave antenna. The + and − signs indicate only the instantaneous polarity, which reverses at the frequency (period) of the signal.

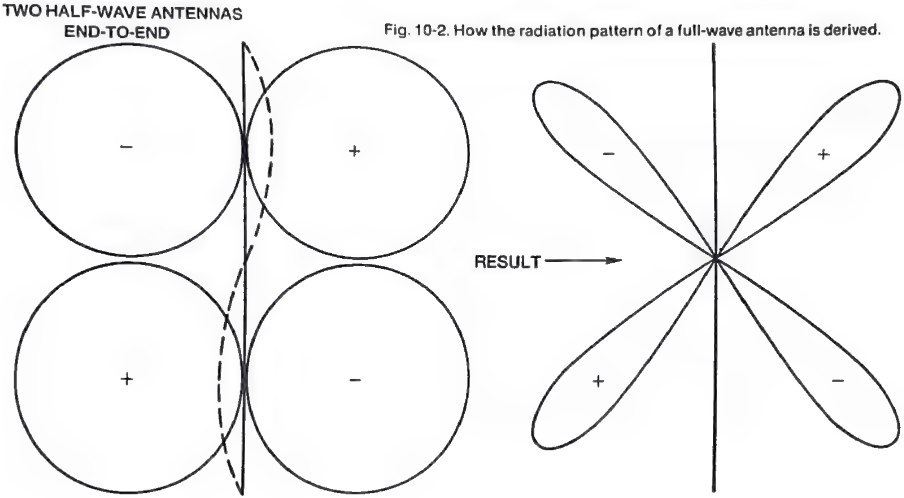



Fig. 10-2. How the radiation pattern of a full-wave antenna is derived.

(Fig. 10-2). However, at any given instant, the polarity of the electric fields from the two segments would be opposite. The radiation straight out from the wire would be cancelled out, leaving two angular lobes at 45° to the wire.

Now, if we add a third half-wave segment, we have the combined patterns of a full- and a half-wave antenna (Fig. 10-3).

Adding still another half-wave segment, making two wavelengths in all, we end up with a pattern resembling the combined patterns of two full-wave antennas competing with one another.

We can now see how the radiation pattern of a long wire adds a pair of lobes for each wavelength of wire. After four or five wavelengths the lobes seem to combine to give the antenna some real directivity. While there are numerous minor lobes allowing some reception and radiation in all

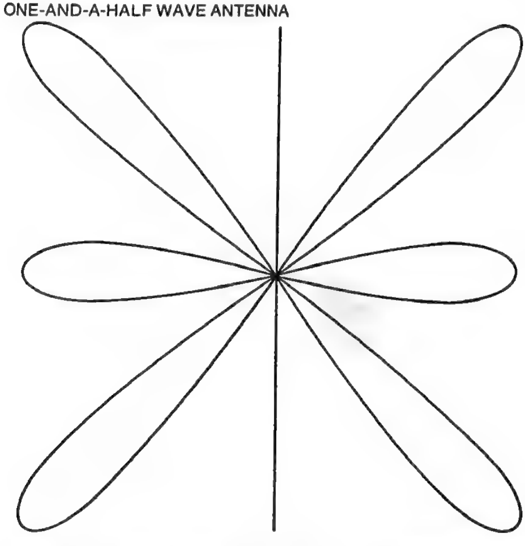



Fig. 10-3. This pattern results when three half-wave antennas are combined into one antenna a wave-and-a-half in length.

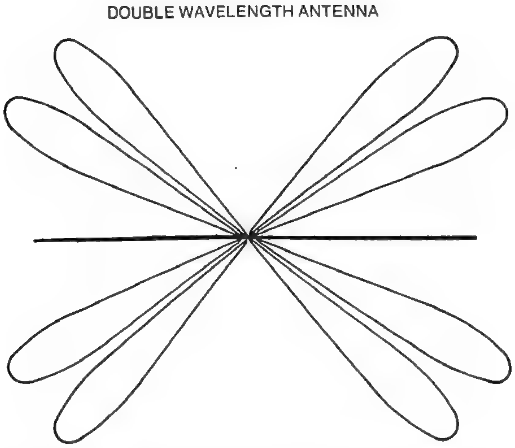



Fig. 10-4. Here, two full-wave antennas are combined to make a single long-wire antenna. This is a true long-wire antenna.

directions, the major lobes prevail and the directivity is pronounced.

There are some practical limits to the length of conductor that can be used. Beyond 15 wavelengths or so the resistance of the conductor becomes predominant enough that the directivity added by more wire is not worth the loss in efficiency due to added resistance. The length of a multiwave antenna is calculated from the formula:

$$L\,(\text{FEET}) = \frac{984\ (N-0.025)}{F}$$

F = Frequency in MHz
N = Number of full waves

There are two preferred ways of feeding a long wire. It can be fed at the end, either by link coupling the transmitter into it through a parallel-tuned circuit, or directly through an L network; or it can be opened at a current loop and fed with a low-imepdance line (Fig. 10-5). Remember that the current is 90° out of phase with the voltage, so a current loop exists at a

voltage node. Voltage nodes exist at odd multiples of quarter wavelengths from the ends.

## TRAVELING-WAVE ANTENNA

A nonresonant long wire, terminated in its characteristic impedance, is called a traveling-wave antenna. It really is a very lossy, terminated transmission line, the other conductor being the reflection of the conductor in the ground. It is highly directive, but unlike other long-wire antennas, it is *uni*directional. A wave front traveling from the termination to the receiver sweeps along the wire inducing electrical currents as it does so. Succeeding waves combine to add, supplying considerable voltage to the receiver, if the wave is coming from the right direction. Waves coming from the opposite direction lose all their power in the terminating resistor. This type of antenna is primarily suited to reception.

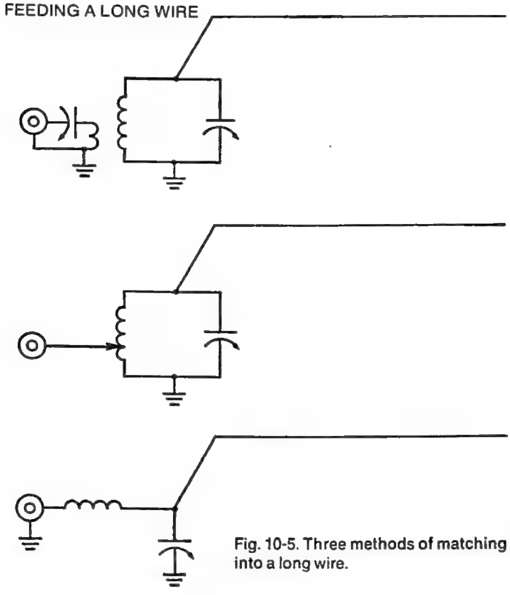



Fig. 10-5. Three methods of matching into a long wire.

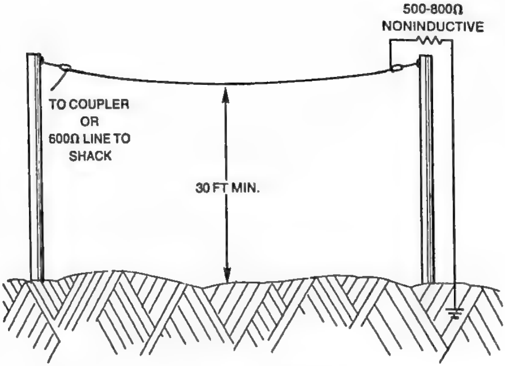


Fig. 10-6. Nonresonant long wire or Beverage antenna.

It will work with the same directional pattern as a radiator, but as half the power is dissipated in the resistor, it is not very efficient.

## NONRESONANT OR BEVERAGE ANTENNA

An antenna of the type shown in Fig. 10-6, *30 feet* or so off the ground, has a characteristic impedance of about 500 ohms. Since it is terminated in its characteristic impedance, the frequency does not affect the characteristic impedance. The resistor used to terminate this type antenna should be noninductive, and if used for transmitting, should have a power rating at least half the power output of the transmitter.

Most of the antennas heretofore described require a conductive ground beneath it. The exception to this rule is the Beverage. The Beverage is a nonresonant long-wire that can be as short as one wavelength, suspended only 10 to 20 *feet* above the ground. Like other nonresonant long wires, the Beverage has a characteristic impedance of 200 to 500 ohms. It is highly directive in the direction from the receiver to the terminating resistor. Unlike other antennas, it performs best over a ground that has very poor conductivity. The worse the ground conductivity, the better a Beverage performs. It is better suited to reception than to transmission. This and all nonresonant long-wires must be run in a straight line.

## Gain and Directivity

The gain of any of these long-wire antennas can be increased by installing several antennas parallel to one another, then feeding them in phase (Fig. 10-7). This phasing can be accomplished by having an identical length of cable running from the transmitter or receiver to each antenna. If just two antennas are to be fed in phase, join their feed points with a piece of cable and run a line from the exact center of this cable to the equipment.

Directive arrays for the lower amateur bands can be constructed in a manner similar to beam antennas used on the VHF bands. That is, half-wave elements can be properly spaced with respect to one another to obtain a directional pattern. Except that they can't be rotated, their behavior is identical to that of a VHF beam.

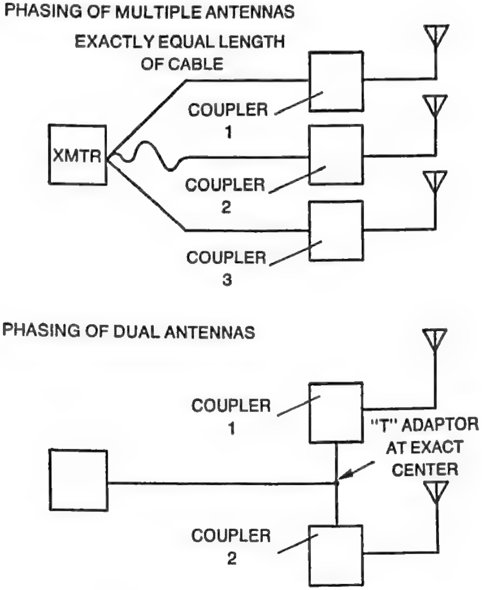



Fig. 10-7. How to feed two antennas in phase.

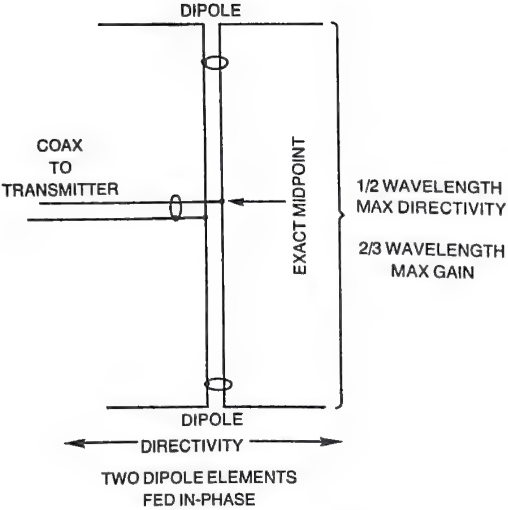



Fig. 10-8. Feeding a phased array.

We can also position two dipoles side-by-side and feed them in phase. This causes the directional patterns of the two antennas to reinforce one another. However, it can also become a very tricky proposition. Each dipole element is a tuned circuit, and the mutual coupling between them greatly changes the feed-point impedances, especially when all elements are driven. That is, when power is fed from the transmitter to each of the elements.

If the elements are fed in phase with one anotner, the directional pattern is parallel to the elements (off the ends of the dipoles, that is) broadside to the axis of the array (Fig. 10-8). Such an array is said to have a broadside directional pattern. The pattern is sharpest when the elements are spaced 1/2 wavelength apart. The pattern is not so sharp, but the gain is a couple of dB higher when the spacing is only about 2/3 wavelength. If only two elements are used no minor lobes exist; minor lobes are always present with three or more radiators.

Feed-point impedance can become a major problem depending on the spacing between the radiators. However, when the spacing is kept from one-half wavelength to two-thirds wavelength, the impedance at the center of either dipole is about 50 to 75 ohms, and the array becomes manageable.

**End Fed Array**

If the elements are fed 180° out of phase with each other, accomplished by having one dipole element fed with an extra half wavelength of feedline, the directional pattern becomes at right angles to the direction of the conductors. That is, it is in-line with the axis of the array. This is known as an end-fire array (Fig. 10-9). With respect to feed-point impedance of an end fed array, it is in the neighborhood of 50 ohms when the elements are spaced about 1/3 wavelength, and closer to 75 ohms when the elements are spaced slightly more than 4/10 wavelengths.

Power gain is greatest when the elements are only 1/8 wavelength apart. At that spacing the feed-point impedance at the center is only 8 ohms or so, creating some matching problems. When the elements are 1/3 wavelength apart, thereby presenting a more workable impedance, the gain is only 1.5 dB less than when they are closely spaced. Gain is least when the elements are spaced 2/3 wavelengths.

**Colinear Array**

Two or more antennas positioned in a straight line end-to-end are called a colinear array. They are always fed in phase—if they were fed out of phase, the system would simply become a very expensive long wire (Fig. 10-10). Colinears are sharply directional at right angles to the array, and the more half-wave elements that are used, the sharper the directivity. For practical reasons, these arrays seldom use more than four elements. A four-element array presents, in addition to the major lobes, minor lobes at 45° to the array.

While the elements of a colinear array can be fed with coax going individually to the center of each, there is a much more practical method. One element is fed at the end, and a 1/4 wave stub connects between each succeeding element. Each 1/4 wave stub delays the signal by 180° from one element to the next with the result that the current travels in the same direction in each element, and is thereby in phase.

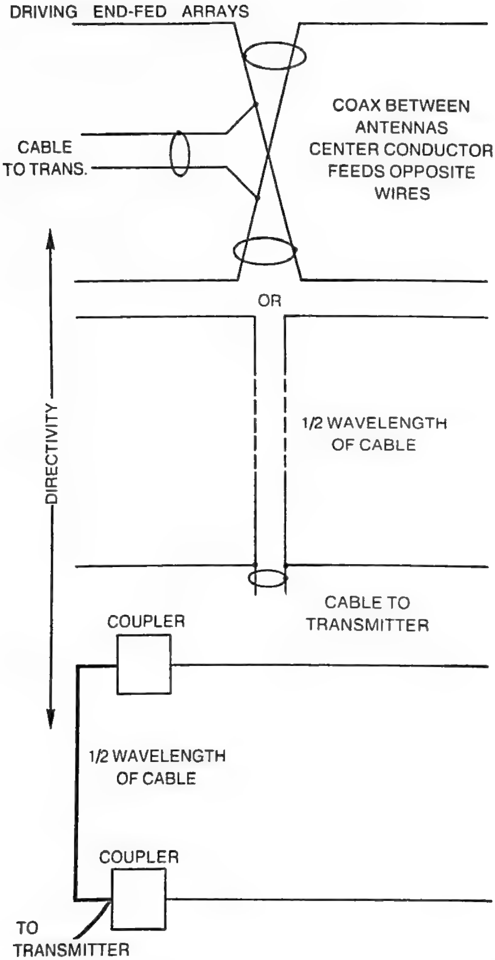



Fig. 10-9. Three methods of feeding two dipoles 180° out of phase.

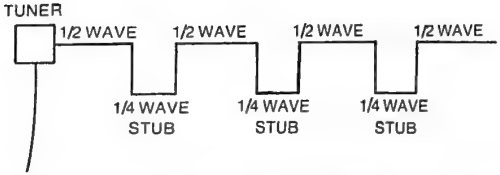



Fig. 10-10. A 4-element colinear array. The quarter-wave stub between each element and its successor provides a 180° phase difference. Thus each element is in-phase with all the others.

The gain of a colinear array is greatest when the elements are spaced slightly more than 1/2 wavelength between adjacent ends, but only 1.5 dB or so less than maximum when the elements are separated by nothing more than an insulator. Further discussion of colinear antennas can be found in Chapter 11 on VHF antennas.

### V-Beam

It was mentioned earlier in this chapter that the directivity of a long-wire antenna several wavelengths long is quite pronounced at an angle to the wire. Now, if two long wires are placed at such an angle to each other as to reinforce the major lobe, and fed out of phase, the directional pattern is enhanced along the common axis of the two. Such a system, because of the consequent positioning of the antennas, is known as a V-beam (Fig. 10-11).

The optimum apex angle of a V-beam depends somewhat on the number of wavelengths in each leg, but for antennas

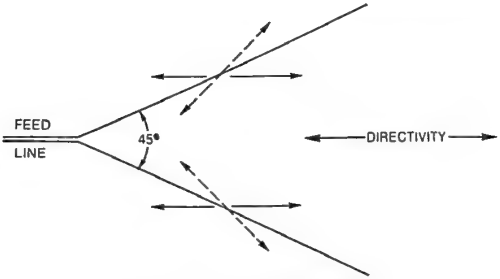



Fig. 10-11. A 4-wavelength V-beam.

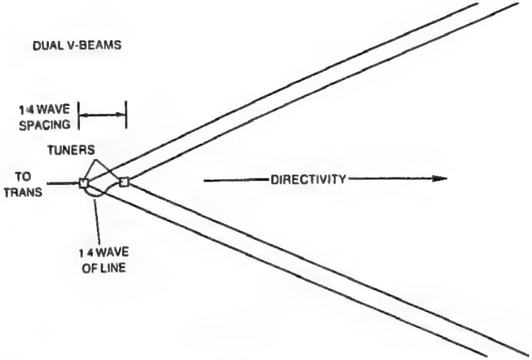



Fig. 10-12. Two V-beams 1/4 wavelength apart, 90° out of phase provides a unidirectional pattern.

greater then four or five wavelengths, is not extremely critical. A rough approximation of the optimum angle is given below:

| WAVELENGTH | ANGLE |
|---|---|
| 1 | 110° |
| 2 | 70° |
| 3 | 55° |
| 4 | 45° |
| 5 | 40° |
| 6 | 35° |
| 7 | 32° |
| 8 | 28° |

From this we can see that, when a V-beam is operated on several harmonically related bands, a reasonable compromise in apex angle is not extremely hard to achieve.

Unidirectional operation can be achieved by placing two V-beams in line with each other and feeding them with a phase difference of 90° (Fig. 10-12). They should be spaced about a quarter-wavelength apart. The directional pattern is unidirectional from the 0° to the 90° antenna.

V-beam antennas are best fed at the apex, either with a coupler or with tuned feeders. There is no real reason why you couldn't center-feed the two antennas with coax, other than the

expense. If you try it, however, be sure they are correctly phased, and fed at current loops.

**RHOMBIC ANTENNAS**

When two V-beams are placed mouth-to-mouth, the resulting diamond formation is known as a rhombic antenna. A rhombic has a low-angle pattern that is very directional along the major axis, and has a measurably greater gain than a V-beam using the same amount of wire. The rules governing the apex angle are essentially the same as those governing the apex angle of a V-beam, the angle of a rhombic being dependent on the number of wavelengths per side.

Like a V-beam, a rhombic must be fed with tuned feeders. Contrary to popular belief, if the rhombic is truly resonant, no terminating resistor is needed. The ends are simply brought to an insulator and left open.

On the other hand, if a rhombic is to be used as a nonresonant antenna the remote ends are joined with a resistance approximately equal to the characteristic impedance of the antenna as a unit. A nonresonant rhombic is the ultimate development in a wire antenna.

The basic principles of a nonresonant rhombic are the same as for the resonant variety. There is an optimum leg length for a given wave angle as shown below:

| Angle | Length |
|---|---|
| 0 to 15° | 6 |
| 20° | 4.25 |
| 25° | 2.75 |
| 30° | 2 |

These dimensions are, of course, very tolerant of variations in frequency. Leg lengths beyond six wavelengths are impractical due to the sharpness in pattern. At six wavelengths per leg, a nonresonant rhombic has a gain of 12 dB over a dipole, this figure including the loss produced by the terminating resistor.

While there is really no marked difference in gain between a resonant and a nonresonant rhombic, the nonresonant variety is preferred for its very broadband characteristics. Furthermore, a nonresonant rhombic is more nearly unidirectional, from the feed end toward the terminated end, while the resonant variety is bidirectional. The power lost in

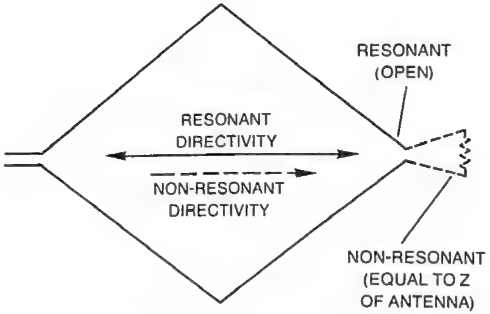



Fig. 10-13. The rhombic. Without the loading resistor, and cut to an exact multiple of wavelengths, it is bidirectional. With the terminating resistor, it is nonresonant and unidirectional.

the terminating resistor is simply that which would be radiated in the back direction if the resistor were not there. Of the remaining power, about half is radiated in minor lobes, and the rest radiated as a major lobe. The value of the resistor is in the neighborhood of 800 ohms. For most applications this value will do nicely. Those who are really fussy about performance will have to experiment.

The resistor used must be of the noninductive type. Specially designed resistors are manufactured for this purpose, or the enterprising amateur can try using a number of carbon resistors in parallel. Most of the leading manufacturers make noninductive resistors in power ratings up to a couple hundred watts. This can be greatly increased by immersing the resistor in a can filled with either mineral oil or transformer oil, the latter being preferable. This scheme can put a termination suitable for the legal amateur maximum within reach of the average working man. If you have trouble finding where to order one, contact any major *industrial* electronic parts distributor. Specify that you need either a noninductive resistor with a power rating half that of your transmitter, or a rhombic antenna termination resistor. If your rhombic is to be used only for listening, a low-wattage carbon resistor will do fine.

## PHASING VERTICAL ANTENNAS

It has already been discussed that two antennas spaced a quarter wavelength apart and fed 90° out of phase can have a unidirectional pattern. This scheme is used frequently by broadcasting stations to provide a null in their radiation pattern to prevent interference with a station in some other locality. Phased antennas can be used by amateur stations either to direct their signal toward a given area or to provide a null.

Phasing can easily be accomplished by varying the length of coax between the towers. Figure 10-14 shows one simple arrangement. The directivity is from the leading-phase tower toward the lagging-phase tower.

If the towers are spaced a half wavelength apart and fed 180° out of phase, the resulting directional pattern is bidirectional, in line with the towers. Feeding the towers in phase results in a bidirectional pattern at a right angle with the line of the towers (Fig. 10-15). In either arrangement, remember to take the velocity factor of the cable into consideration when cutting a quarter-wavelength feedline. Use the formula

$$L = \frac{246\,V}{F}$$

where F is the frequency in megahertz and V is the velocity factor of the particular line used.

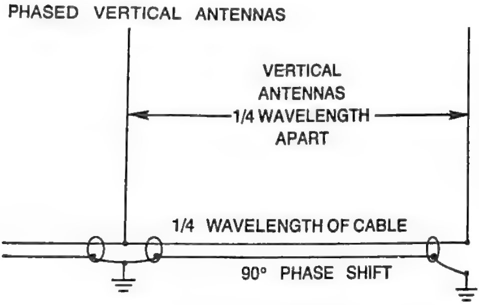



Fig. 10-14. Feeding two vertical towers out of phase for a unidirectional pattern.

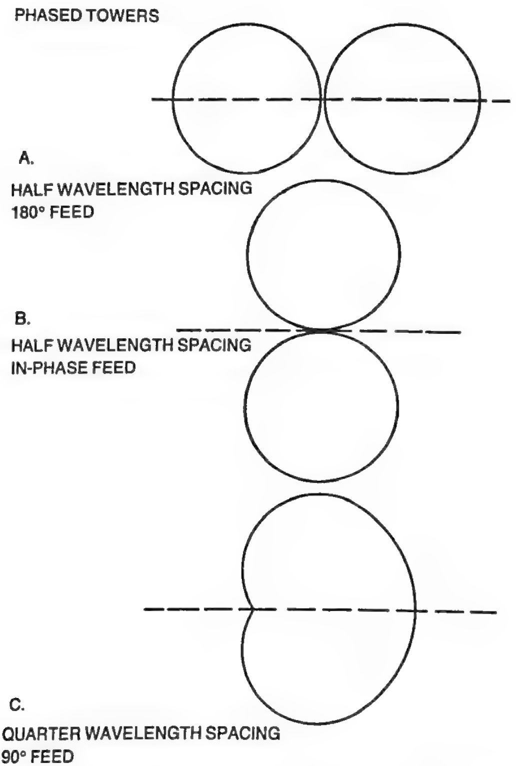



Fig. 10-15. Directional patterns resulting from phasing of towers. The dotted lines indicate the centerline of the two towers. A is the pattern that results from feeding the towers 180° out of phase. B results when the towers are fed in phase. C results from towers 1/4 wave apart fed 90°.

## QUAD ANTENNAS

Quad antennas are hardly what one might call space hogs. On the other hand, they are sufficiently more demanding than parasitic beams to merit space as directive arrays. The name implies four, and that's where a quad begins—a quadrangle,

each side a quarter-wavelength long. Don't let it fool you. It is in reality a full-wave loop antenna.

You will recall, from Chapter 8, that a full-wave loop radiates at right angles to the plane of the loop. This principle is where the quad finds its first advantage. The loop, supported upright, can be backed up with other loops, differing slightly in size, which can then form reflectors and directors, giving the directional characteristics of a Yagi, or parasitic beam. Thus rotatable directional antennas can be produced that perform as well as a Yagi for wavelengths that would make a Yagi unwieldy.

The actual loops of the quad can be closed, having a fairly high impedance, or they can be open, a low impedance able to be fed with coax. Feed-point impedance varies somewhat with the spacing of the wires. For spacing from 0.15- to 0.2-wave-length, feed-point impedance is in the order of 40 to 60 ohms for a closed loop. This may seem to contradict what was just said, until you increase the spacing to 1/4 wavelength and find the feed-point impedance to be 80 or 90 ohms, requiring a quarter-wave stub or other matching device.

Generally speaking, a quad has about 2 dB more gain than a Yagi with a similar number of elements and a similar boom length. Otherwise, beam width, front-to-back ratio, and other directional antenna factors compare quite favorably. The basic configuration of a quad appears in Fig. 10-16.

For a three-element quad, the circumference of the elements can be calculated with the formula:

$$\text{Reflector C} = \frac{1030}{F}$$

$$\text{Driven element C} = \frac{1005}{F}$$

$$\text{Director C} = \frac{975}{F}$$

In each case the circumference is given in feet, and the frequency in megahertz.

There has, in the past, been some disagreement over whether to mount the quad with the spreaders vertical and horizontal, or with the wires vertical and horizontal. Generally

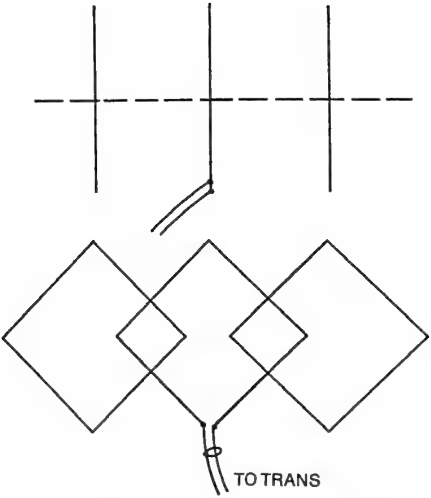



Fig. 10-16. Basic configuration of a quad.

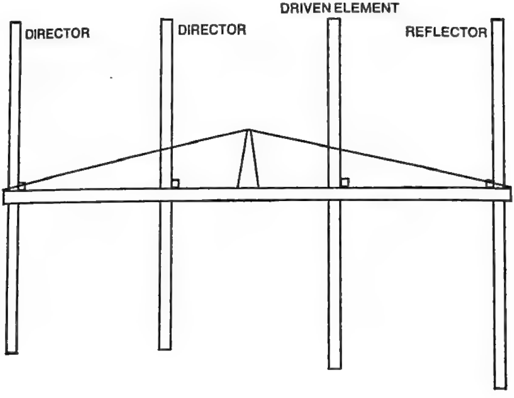



Fig. 10-17. Director and reflector details of K2GAT quad.

speaking, mechanical and other factors recommend that the spreaders be vertical and horizontal in areas where ice may accumulate in the winter. As to performance, there is no difference worth quibbling about.

Jake Kaufman, K2GAT, offers the design for a three-band quad shown in Fig. 10-17. He used it for several years until it finally succumbed to a severe ice storm, along with the antennas of a great many other amateurs in Western New York. It consisted of four elements on each band, and was mounted in a diamond position with the feed at the bottom.

The spacing between elements was the same for all bands, about 7 1/2 feet. Separate feedlines were used, since Jake felt coax was cheaper than a remote switch. The elements were supported on a 22 1/2-foot boom. Spreaders were made of fiberglass rod for the horizontal and the top part of the vertical arms. The bottom part of the vertical arms were made of aluminum. All of the aluminum parts were electrically connected together and grounded. When the wire loops were attached to the spreaders, they were grounded to the aluminum arms. This grounding eliminated the capacitive effect of his

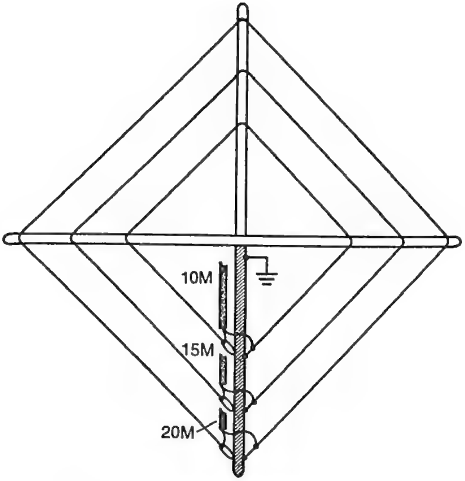



Fig. 10-18. Driven element details of K2GAT quad.

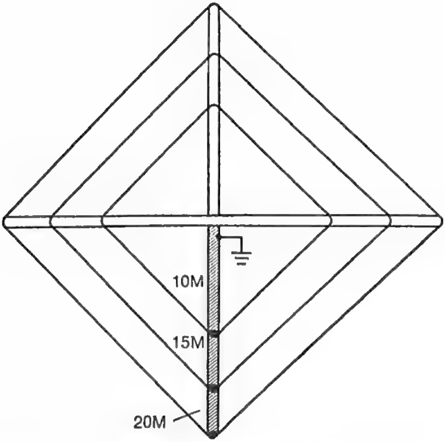



Fig. 10-19. How quad elements are mounted on boom. The bottom leg of each loop is made of aluminum. They are all connected together along the boom. The boom is reinforced by guy lines running to a small, vertical support at the center.

body when he final-tuned the antenna, and got rid of a +200 kHz discrepancy in the mathematical calculations.

With the elements properly grounded, the insensitivity of loop antennas to static was very evident. Using four elements at the spacing shown offered a good match to 52-ohm coax, eliminating the need for matching devices.

Unlike most directive arrays, Jake's quad had no difference in size between the two directors. Also, as mentioned earlier, the spacing between elements was held at 7 1/2 feet for all bands, greatly simplifying construction. He initially tuned his quad with the boom about 14 feet above ground, putting the bottom ends of the spreader arms barely off the ground. When he raised the boom to its final 33-foot height, the resonance of the elements moved about 25 kHz. Otherwise, Jake says, the formulas are accurate.

# Chapter 11
# VHF and UHF

Antennas discussed so far have been for frequencies below 30 MHz. Above that frequency, which is generally agreed upon to be the dividing line between high (HF) and very high frequencies (VHF) lies a spectrum many times larger than all the frequencies below it. The world of VHF and UHF is unique. Like the lower portions of the spectrum, it has its advantages and its disadvantages.

Antennas for very high frequencies are much more compact, therefore easier to build. At the same time, however, they are much more critical in size tolerances. Being smaller than antennas for the lower bands, VHF antennas can be made sharply directional thus concentrating nearly all the power right where you want it.

VHF bands are daily becoming more popular in the mobile world, especially two meters. This is partly due to channelization and the availability of repeaters, and partly due to the compactness of antennas and the highly efficient car roof ground plane resulting from the shorter wavelengths.

## GROUND PLANE WHIPS

Since VHF frequencies are rarely propagated by the ionosphere with its dispersing effect, polarization is of greater consequence. Transmitting and receiving lines can lose 20 dB by having cross-polarized antennas.

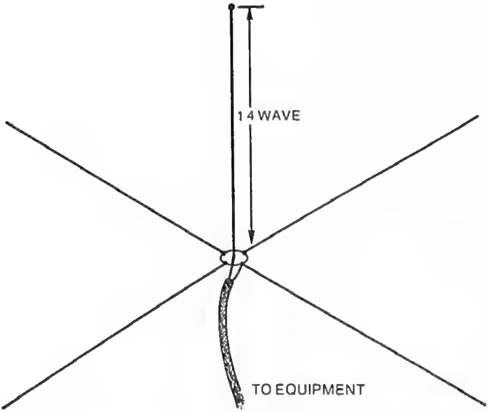



Fig. 11-1. The ground-plane antenna. The radials simulate a ground, and are connected to the shield of the coax. The center lead of the coax is connected to the vertical element.

The simplest VHF antennas are vertically polarized whips one-quarter-wavelength long, of which the best known is the ground plane. A ground-plane antenna consists of a quarter-wave, vertical-driven element which relates to an artificial ground. The artificial ground consists of three or four radials, positioned horizontally, and electrically connected to ground.

The radials should be at least a quarter-wavelength long. If they are perfectly horizontal, the feed-point impedance is in the neighborhood of 34 ohms; angling the ground radials downward at 45° raises the feed-point impedance to 50 ohms, making it an ideal match for standard coax cable. Even without angling the radials, however, the mismatch is still slightly less than 1.5 to 1.

Ground planes for six meters can be built of copper tubing and fittings, while a two-meter antenna can be built with five pieces of welding rod and an SO-239 connector (Figs. 11-1 and 11-2). Because of the unknown velocity factor and the diameter-to-wavelength ratio, it is a good idea to cut the tubing or rod an inch or so longer than calculated, then prune it for

the best SWR. Prune your antenna very carefully, however. At two meters, 1/2 inch can make a difference of 4 MHz!

Mobile antennas for the two-meter band are frequently ground planes even though they may not look it. Often you see only a small whip sticking out of the roof or the trunk lid. Sometimes they are simply held in place by a magnetic base. Such antennas utilize the car body as a ground plane, coupling to it capacitively right through the paint. At these frequencies, if the capacity between the magnetic base and the car body on the other side of the paint were only 10 pF, it would have a reactance of less than one ohm.

Many variations of the quarter-wave vertical antenna appeared in the years before coax became popular and plentiful. Often the amateur had to make do with whatever he could scrounge. One example is shown in Chapter 9, where a series-tuned circuit is used to match the antenna to virtually any kind of line. This, of course, can get a bit hairy at frequencies in the VHF range. However, there are a couple of neat tricks you can use.

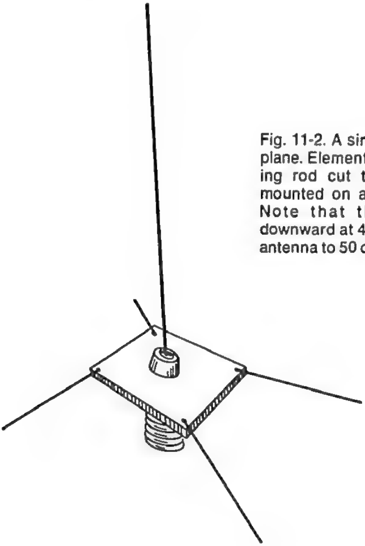


Fig. 11-2. A simple 2-meter ground plane. Elements are pieces of welding rod cut to length. They are mounted on a SO-239 connector. Note that the radials angle downward at 45°. This matches the antenna to 50 ohms.

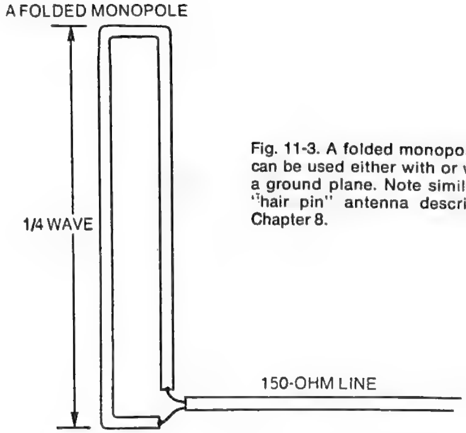



Fig. 11-3. A folded monopole. This can be used either with or without a ground plane. Note similarity to "hair pin" antenna described in Chapter 8.

Two quarter-wave antennas can be connected together as shown in Fig. 11-3, resulting in a fourfold increase in impedance. The fourfold increase results from the current being shared by two antennas, with each antenna carrying half the current of a single antenna. Now, power is determined by the *square* of the current. Since the amount of power remains the same, and only half the current flows, by Ohm's Law, the impedance is quadrupled, bringing the feed-point impedance within a reasonable match to 150-ohm line.

By the same principle, we can feed three antennas to make a decent match for 300-ohm line (Fig. 11-4). This scheme is quite useful for police monitors in cases where old receivers with 300-ohm inputs are used.

Numerous antennas like those described in previous chapters are in use in the VHF bands. The 5/8-wave whip (Chapter 9) is fast catching up with the quarter-wave whip. Colinear antennas are coming into widespread use, the popular "Ringo Ranger" being a classic example. Also, at these frequencies the DDRR sees some use.

## THE DISCONE ANTENNA

Figure 11-5 is a vertically-polarized antenna in a class all by itself. It covers an extremely broadband of frequencies,

being useable over a range of several octaves. The dimensions depend primarily on the *lowest* intended frequency of operation. The cone portion should have a base diameter of a quarter wavelength in free space, as should the hypotenuse of the cone cross-section. The disc has a diameter of 0.68 times the diameter of the cone base. The space between the disc and the cone is 6 inches at 14 MHz, and 1 inch at 144 MHz. With these two points as a guide, the spacing can easily be estimated for any frequency. It is not extremely critical.

The cone can be made of a solid piece, of screen, or of wire radials spaced no more than 1/50 wavelength at the bottom. Feed it with 50-ohm coax and you should have good SWR over a 10-to-1 range.

### THE J-BAR ANTENNA

The antennas described so far in this chapter have been those that are normally vertically polarized. There are, of course, a wide variety of antennas that can be positioned either way, especially at VHF frequencies. Most of these are mutations of our old friend, the half-wave antenna.

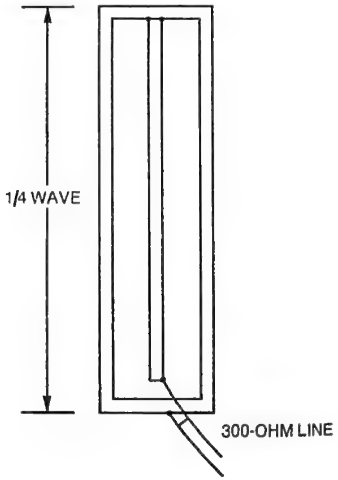



Fig. 11-4. A 300-ohm vertical.

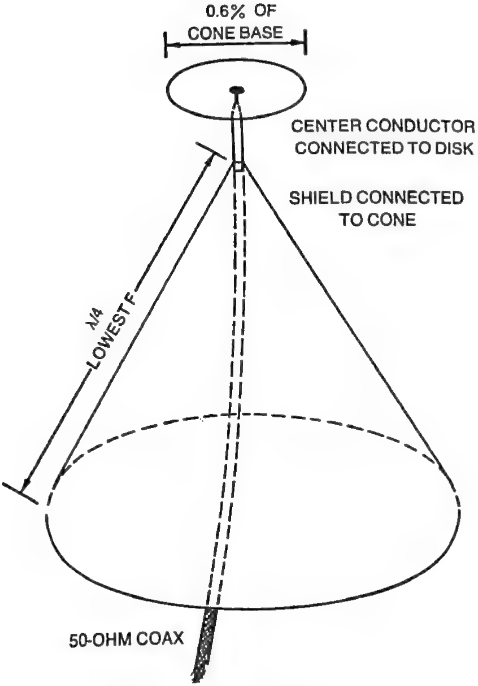



Fig. 11-5. The discone antenna.

Of course, this writer seldom discusses half-wave antennas without mentioning end-feeding. Only one end-fed, half-wave antenna exists for VHF, that I know about, and that's the J-bar. The J-bar is simply a half-wave antenna fed through a quarter-wave matching stub. At these frequencies, regular coil-and-capacitor, tuned-circuit elements become small in value and touchy to tune. The quarter-wave, shorted stub comes to the rescue, resulting in the J configuration (Fig. 11-6).

In calculating the length of the elements, the use of tubing, the presence of the stub, and a few other factors alter the

formula slightly. Calculate the half-wave section from the formula:

$$L\,(\text{inches}) = \frac{5540}{F\,(\text{MHz})}$$

Calculate the length of the stub from the formula:

$$L\,(\text{inches}) = \frac{2880}{F\,(\text{MHz})}$$

The bottom of the J may be grounded, simplifying mounting. To feed with coax, ground the bottom of the shorter element and connect the center lead of the coax to the longer element. Adjust the shorter element for minimum SWR. To feed with a higher impedance line, tap the line into the

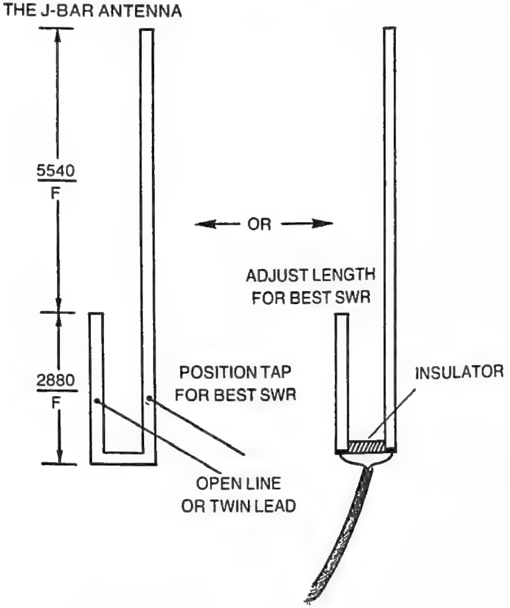



Fig. 11-6. Two methods of feeding the J-bar.

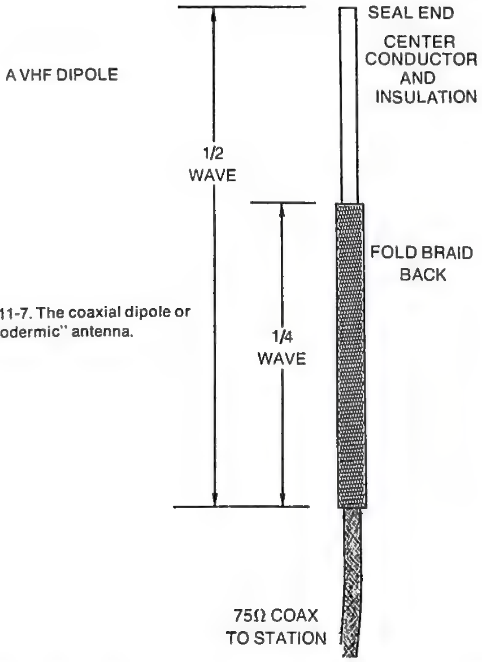



Fig. 11-7. The coaxial dipole or "hypodermic" antenna.

quarter-wave section, adjusting its position for minimum SWR.

## A SIMPLE VHF DIPOLE

The basic, half-wave dipole can be quickly constructed for any VHF frequency, using copper tubing or aluminum conduit. The small size and rigid construction permits either vertical or horizontal mounting. In the vertical position problems can arise from the presence of the coax, the outer conductor of which is grounded, running along parallel to one of its elements.

This can be solved, either by end-feeding as already discussed, or by using the coax itself to form the antenna (Fig. 11-7). The shield is doubled back over the outer covering of the

coax for a quarter wavelength, and the exposed center conductor left sticking out in a straight line. This results in two quarter-wave elements fed at the center with matching coax, in other words, a dipole. Called a hypodermic antenna by some of its fans, it has wide use whenever a cheap, quickie antenna is needed. Just remember, if you have to prune it, prune *both* the center conductor and the doubled-back portion of outer conductor uniformly.

## THE FOLDED DIPOLE

Utilizing the same principle described on the preceding page, two dipoles can be connected in series with one another to form a folded dipole (Fig. 11-8). This configuration has a feed-point impedance in the neighborhood of 300 ohms, and is the classical TV antenna element of the late forties and early fifties. While other configurations have since come into use, the folded dipole is still used in many instances for TV and FM broadcast reception. It is very simple to construct and offers a good match to the cheap and readily available twinlead. The main disadvantage of a folded dipole is that it is difficult to prune.

At Fig. 11-8B, though, is a simple scheme to precisely resonate a folded dipole. The clamps for the ends can easily be made from sheet stock. Just be sure that, when you adjust this antenna, you keep both clamps equally distant from the center. Another convenience to bear in mind is that the center of the top portion of this antenna can be grounded, greatly facilitating mounting onto a metal boom as part of a Yagi.

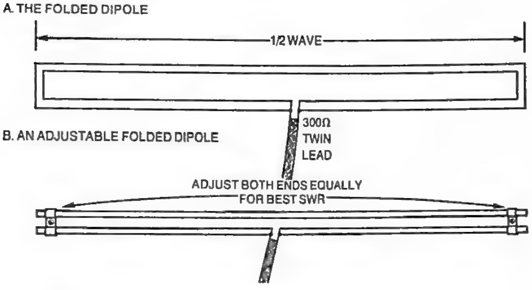



Fig. 11-8. The folded dipole (A) and an adjustable folded dipole (B).

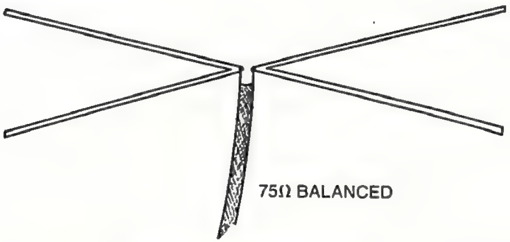



Fig. 11-9 The conical dipole.

If you mount this, or any center-fed dipole in a vertical position, be sure to extend the feedline straight out from the antenna for at least a wavelength before making a parallel run.

## THE FAN DIPOLE

A fan dipole goes under various names in the VHF range. Called the "bow tie", the conical, etc., it is very popular in VHF and UHF TV reception, although I haven't heard much on its use in VHF amateur transmitting (Fig. 11-9).

## T AND GAMMA MATCHING

For precise matching of a dipole to various line impedances, the T and gamma match provide a near unbeatable combination (Fig. 11-10). The T match is used with balanced line, such as twinlead; and, the gamma match is used with unbalanced lines (coax). While formulas do exist for calculating the dimensions, they are extremely complicated and it often is best to find them experimentally. One popular model uses slide clips to determine the length of the matching section. These are simply adjusted for minimum SWR. Another uses capacitors to trim out the unwanted reactive components: 150 pF has been recommended as maximum capacitance for 20-meter operation, and 15 pF for 2-meter operation (Fig. 11-11). Using the proportion of 7.5 pF per meter of wavelength, you can easily come up with a variable capacitor to cover the range of your chosen band. Receiver-type capacitors should do fine for power levels up to 500 watts or so.

## COAXIAL BALUNS

At VHF frequencies, antenna dimensions are small enough to make a coaxial balun practical (Fig. 11-12). All you do is take a half wavelength of coax and connect it between the two elements. The feedline is then connected to one of these elements. This balun makes a four-to-one step up in impedance. Because of the velocity factor of coax, the actual length of the half wavelength line comes out to be 0.33 times the corresponding wavelength in free space. Most amateurs using this scheme prefer simply to tape the stub against the existing feedline with electrical tape.

## FOCUSING SIGNALS

A great number of antenna styles exist. All have their own merits. But to keep this book concise, only the most popular have been covered. After selecting your driven element, the next step is to focus the transmitted power wherever you want it to go.

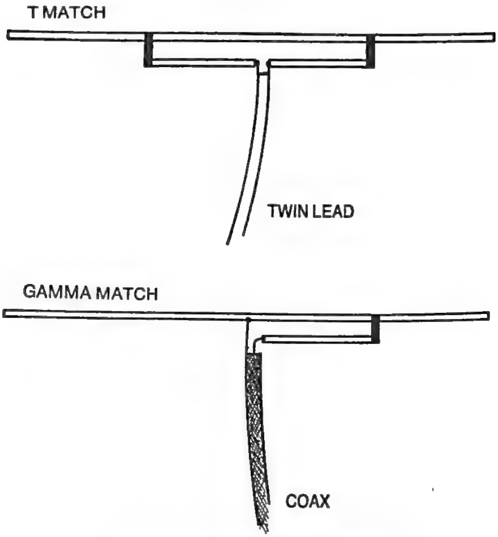



Fig. 11-10. T match and gamma match.

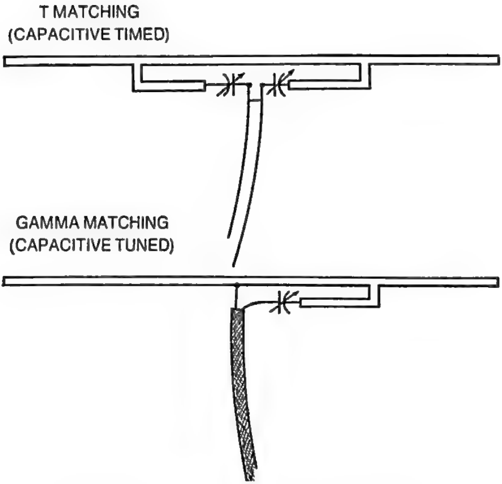



Fig. 11-11. Adjustable T match and ,gamma match

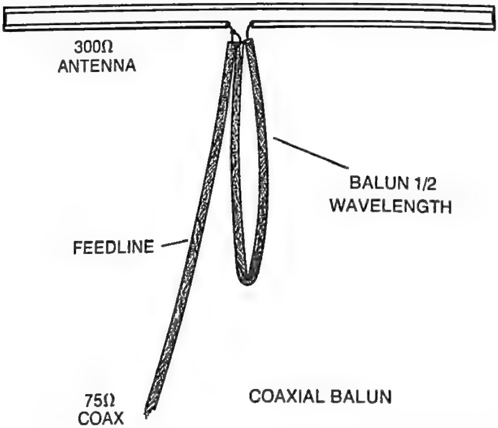



Fig. 11-12. Coaxial balun. Use 1/2 wavelength total for the matching section. This balun is often used to match coax to a folded dipole.

**The Yagi Antenna**

The simplest of the multielement, directional antenna is the Yagi, named after the man who mathematically explained its principles of operation. Rather than go into this heavy math we will confine our discussion to this general explanation. Begin with a dipole picking up a signal. A receiver connected to that dipole will indicate a certain signal strength. If you then place a slightly longer antenna element parallel to the dipole, on the side away from the signal source, the signal strength at the dipole increases. The new element acts like a reflector, reflecting additional signal into the dipole. Now take another element, slightly *shorter*, and place it between the dipole and the signal source. Again signal strength at the dipole increases, the shorter element acting as a director to channel more signal into the dipole.

Neither of the two new elements presented an electrical connection to the dipole, yet each one affected its operation, relying on the currents in the dipole to induce currents in these new elements, which in turn reinforce current in the dipole. Such elements are called parasitic elements—only the driven element is directly connected to the equipment.

**Element Length.** The driven element of a Yagi can be any kind of half-wave antenna you care to make—dipole, folded dipole, conical. All work equally well with parasitic elements. Although sources give no simple formula for computing the length of parasitic elements, a simple pattern is evident. Generally an array contains only one reflector, which is 4% to 5% longer than the driven element (Fig. 11-14). Directors can be of any number as many as you want to fuss with, but two or three are most commonly used. The first director is 4% to 5% shorter than the driven element; the second director 4% to 5% shorter than the first director. Now the percentage factor begins to change. For the third and fourth directors, the difference in length from the *preceding element* becomes only 2% to 3%. While some people do construct monsters of 10 or more elements, stacked arrays should be considered when more gain is required than that available from 4- or 5-element beams.

**Element Spacing.** The spacing between the elements should average between 0.15- and 0.2-wavelengths, with some being spread as much as a quarter wavelength. Spacing affects the bandwidth of the array, closer spacing making it

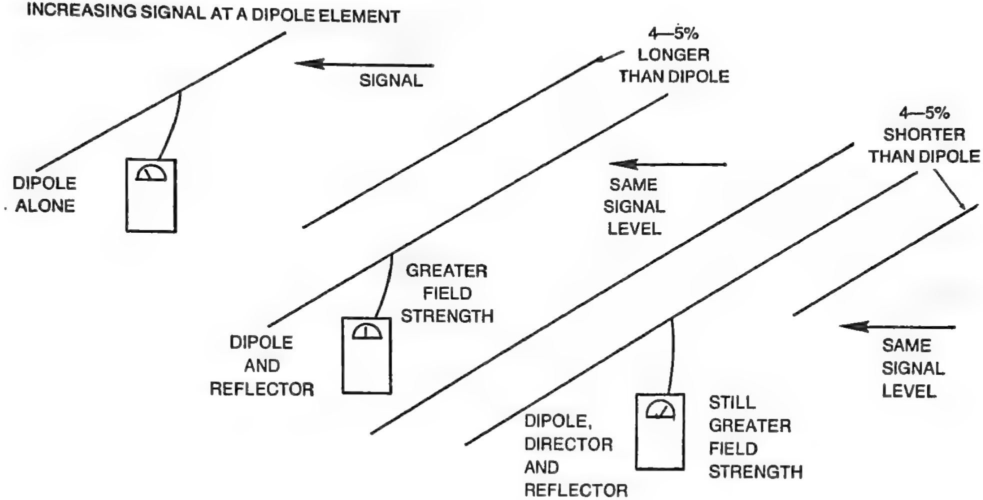



Fig. 11-13. How a Yagi works.

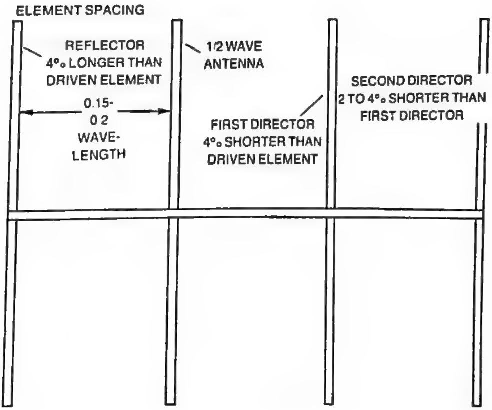



Fig. 11-14. Mechanical specifications for a yagi antenna.

narrower. Here again, if you want to peak the array for the greatest possible gain, it pays to experiment. Connect the driven element to a field-strength meter, orient the antenna for maximum pickup from a steady signal, then adjust element spacing to obtain the strongest signal consistent with the desired bandwidth.

When cutting elements for a Yagi, you may find the basic antenna formula to be a bit inaccurate because large-diameter conductors add a new factor to the previous formula. Instead, use the formula:

$$L\,(1/2\text{ wave}) = \frac{5904 \times K}{F\,(\text{MHz})}$$

for the length of a half-wave element in inches. The value of K can be obtained from Table 11-1.

As we move into still higher frequencies, antenna dimensions that would be out of the question on the low bands now become quite attractive. For example, a rhombic with 4-wave-length legs would occupy over 21 acres on the 75-meter band. At 440 MHz, it would occupy only 72 square feet. Even this size, however, is large compared to some of the other antennas able to beam a signal, with the same amount of gain. A Yagi at 440 MHz, for example, would fit on a tabletop.

Table 11-1. Yagi Element-Diameter Constants.

| Conductor diameter in wavelengths | K |
|---|---|
| 0.05 | 0.92 |
| 0.025 | 0.945 |
| 0.016 | 0.95 |
| 0.0125 | 0.955 |
| 0.01 | 0.958 |
| 0.006 | 0.96 |
| 0.005 | 0.962 |
| 0.0005 | 0.97 |
| 0.00005 | 0.98 |

### Flat-Surface Reflectors

You don't have to be proficient in the radio art to have noticed that many UHF TV antennas use a flat screen as a reflector (Fig. 11-15A). Reflectors of this type can be solid sheet metal or they can be a grid of parallel wires. If a grid is used, the wires should be no more than 0.1 wavelength apart—closer if practical. The driven element can be anywhere from 0.1 to 0.33 wavelengths from the reflector. Feed-point impedance varies with the distance of the driven element from the reflector, ranging from 20 ohms at 0.1 wavelength to 100 ohms at 0.33 wavelength. Impedance is 50 ohms when the spacing is about 0.16 wavelength, and 75 ohms when the spacing is about 0.21 wavelength. The reflector itself should be at least 1 wavelength square.

We often see reflectors made as a 60° or 90° angle (Fig. 11-15B). These can produce a gain as high as 11 dB over that of a simple dipole. They should have a diameter of at least 3/4 wavelength and the side length from the mouth to the corner should be about one wavelength. Feed-point impedance with a 90° angle is 50 ohms when the driven element is 0.3 wavelength from the apex of the reflector, and 75 ohms when the driven element is 0.35 wavelength from the apex of the corner. With a 60° angle, feed-point impedance is 50 ohms with 0.45 wavelength spacing, and 75 ohms with 0.5 wavelength spacing.

### Parabolic Reflectors

A parabola is the ultimate reflector. The curve of the reflector is such that parallel beams coming into it are all

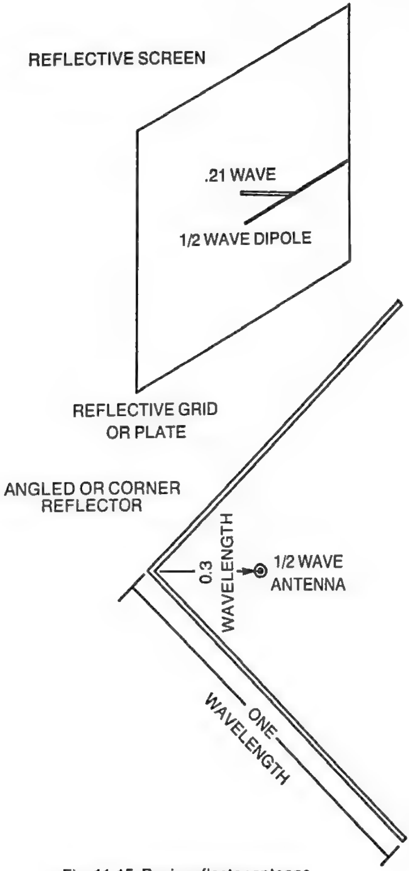



Fig. 11-15. Basic reflector antenna.

reflected to one common point (Fig. 11-16). If the dimensions of a parabolic dish are precisely known, the formula

$$F = \frac{y^2}{4x}$$

will locate the focus: y is the radius, and x is the depth of the "dish". The formula gives the distance straight out from dead center, and any units, either metric or otherwise can be used so long as they are the same throughout.

If you try to build a parabolic reflector, use the same guidelines to determine the distance from the reflector to the focus (where the driven element is located) with regard to feed-point impedance, as specified for plane or corner reflectors. The diameter of the dish should be large with respect to wavelength. The gain is 10 dB when the diameter of the dish is 1.5 wavelengths, and increases by 6 db each time the *area* is doubled.

Here is a handy way to draw a parabolic curve template (Fig. 11-17). Draw a straight line on the template material (A) which will be the axis of the parabola. Draw a perpendicular line at the far side of the template (B). Mark a point at the other side of the template which will be the center of the curve, and locate the focus at the desired distance from the center (C). Fasten a piece of string at the focus point, and loop it around a pencil, at the center of the curve to the guideline drawn in step A (D). Move the pencil above and below the axis,

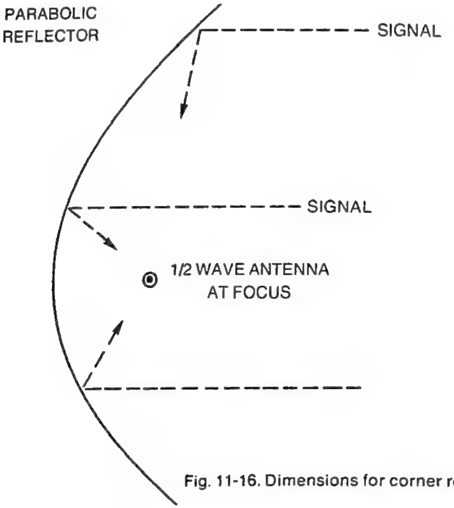



Fig. 11-16. Dimensions for corner reflector.

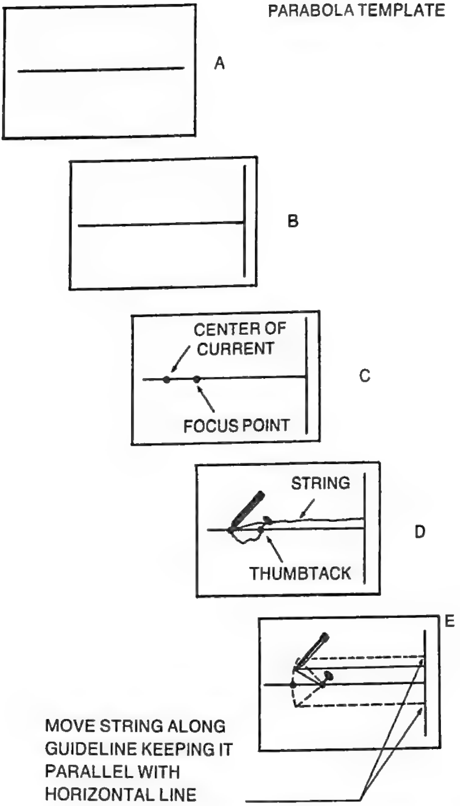



Fig. 11-17. Principle of parabolic antenna. While similar impedance rules hold for the distance between the driven element and the reflector, many UHF antennas use a reflector in which the focal length is several wavelengths, thereby eliminating the influence of the reflector on impedance.

keeping the string on the guideline and holding it tight with the pencil (E). This will trace a parabola that is more than accurate enough for radio work. An error of $\pm 1/8$ wavelength is tolerable.

# Appendix A

# Citizen Band Antenna Regulations

The following is from the FCC regulations applying to CITIZEN BAND antennas, as of April 1976.

**95.37 Limitations on antenna structures.**

(a) Except as provided in paragraph (b) of this section, an antenna for a Class A station which exceeds the following height limitations may not be erected or used unless notice has been filed with both the FAA on FAA Form 7460-1 and with the Commission on Form 714 or on the license application form, and prior approval by the Commission has been obtained for :

(1) Any construction or alteration of more than 200 feet in height above ground level at its site (17.7 (a) of this chapter).

(2) Any construction or alteration of greater height than an imaginary surface extending outward and upward at one of the following slopes (17.7(b) of this chapter):

(i) 100 to 1 for a horizontal distance of 20,000 feet from the nearest point of the nearest runway of each airport with at least one runway more than 3,200 feet in length, excluding heliports, and seaplane bases without specified boundaries, if that airport is either listed in the Airport Directory of the current Airman's Information Manual or is operated by a Federal military agency.

(ii) 50 to 1 for a horizontal distance of 10,000 feet from the nearest point of the nearest runway of each airport with its longest runway no more than 3,200 feet in length, excluding heliports, and seaplane bases without specified boundaries, if that airport is either listed in the Airport Directory or is operated by a Federal military agency.

(iii) 25 to 1 for a horizontal distance of 5,000 feet from the nearest point of the nearest landing and takeoff area of each heliport listed in the Airport Directory or operated by a Federal military agency.

(3) Any construction or alteration on any airport listed in the Airport Directory of the current Airman's Information Manual (17.7(c) of this chapter).

(b) A notification to the Federal Aviation Administration is not required for any of the following construction or alteration of Class A station antenna structures.

(1) Any object that would be shielded by existing structures of a permanent and substantial character or by natural terrain or topographic features of equal or greater height, and would be located in the congested area of a city, town, or settlement where it is evident beyond all reasonable doubt that the structure so shielded will not adversely affect safety in air navigation. Applicants claiming such exemption shall submit a statement with their application to the Commission explaining the basis in detail for their finding (17.14(a) of this chapter).

(2) Any antenna structure of 20 feet or less in height except one that would increase the height of another antenna structure (17.14(b) of this chapter).

(c) All antennas (both receiving and transmitting) and supporting structures associated or used in conjunction with a Class C or D Citizens Radio Station operated from a fixed location must comply with at least one of the following:

(1) The antenna and its supporting structure does not exceed 20 feet in height above ground level; or

(2) The antenna and its supporting structure does not exceed by more than 20 feet the height of any natural formation, tree or man-made structure on which it is mounted; or

Note: A man-made structure is any construction other than a tower, mast, or pole.

(3) The antenna is mounted on the transmitting antenna structure of another authorized radio station and exceeds neigher 60 feet above ground level nor the height of the antenna supporting structure of the other station; or

(4) The antenna is mounted on and does not exceed the height of the antenna structure otherwise used solely for receiving purposes, which structure itself complies with subparagraph (1) or (2) of this paragraph.

(5) The antenna is omnidirectional and the highest point of the antenna and its supporting structure does not exceed 60 feet above ground level and the highest point also does not exceed one foot in height above the established airport elevation for each 100 feet or horizontal distance from the nearest point of the nearest airport runway.

Note: A work sheet will be made available upon request to assist in determining the maximum permissible height of an antenna structure.

(d) Class C stations operated on frequencies in the 72-76 MHz band shall employ a transmitting antenna which complies with all of the following:

(1) the gain of the antenna shall not exceed that of a half-wave dipole;

(2) The antenna shall be immediately attached to, and an integral part of, the transmitter; and

(3) Only vertical polarization shall be used.

(e) Further details as to whether an aeronatical study and/or obstruction marking and lighting may be required, and specifications for obstruction marking and lighting when required, may be obtained from Part 17 of this chapter, "Construction, Marking, and Lighting of Antenna Structures."

(f) Subpart I of Part 1 of this chapter contains procedures implementing the National Environmental Policy Act of 1969. Applications for authorization of the construction of certain classes of communications facilities defined as "major actions" in 1.305 thereof, are required to be accompanied by specified statements. Generally these classes are:

(1) Antenna towers or supporting structures which exceed 300 feet in height and are not located in areas devoted to heavy industry or to agriculture.

(2) Communications facilities to be located in the following areas:

(i) Facilities which are to be located in an officially designated wilderness area or in an area whose designation as a wilderness area is pending consideration;

(ii) Facilities which are to be located in an officially designated wildlife perserve or in an area whose designation as a wildlife perserve is pending consideration;

(iii) Facilities which will affect districts, sites, buildings, structures or objects, significant in American history, architecture, archaeology or culture, which are listed in the

National Register of Historic Places or are eligible for listing (see 36 CFR 800.22 (d) and (f) and 800.10); and

(iv) Facilities to be located in areas which are recognized either nationally or locally for their special scenic or recreational value.

(3) Facilities whose construction will involve extensive change in surface features (e.g. wetland fill, deforestation or water diversion).

Note: The provisions of this paragraph do not include the mounting of FM. television or other antennas comparable thereto in size on an existing building or antenna tower. The use of existing routes. buildings and towers is an environmentally desirable alternative to the construction of new routes or towers and is encouraged.

If the required statements do not accompany the application. the pertinent facts may be brought to the attention of the Commission by any interested person during the course of the license term and considered de novo by the Commission.

# Appendix B

# Amateur Antenna Regulations

The following is from the FCC resulations applying to AMATEUR antennas, as of April, 1976.

**97.45 Limitations on antenna structures.**

(a) Except as provided in paragraph (B) of this section, an antenna for a station in the Amateur Radio Service which exceeds the following height limitations may not be erected or used unless notice has been filed with both the FAA on FAA Form 7460-1 and with the Commission on Form 714 or on the license application form, and prior approval by the Commission has been obtained for:

(1) Any construction or alteration of more than 200 feet in height above ground level at its site (17.7 (a) of this chapter).

(2) Any construction or alteration of greater height than an imaginary surface extending outward and upward at one of the following slopes (17.7(b) of this chapter):

(i) 100 to 1 for a horizontal distance of 20,000 feet from the nearest point of the nearest runway of each airport with at least one runway more than 3,200 feet in length, excluding heliports and seaplane bases without specified boundaries, if that airport is either listed in the Airport Directory of the current Airman's Informatin Manual or is operated by a Federal Military agency.

(ii) 50 to 1 for a horizontal distance of 10,000 feet from the nearest point of the nearest runway of each airport with its longest runway no more than 3,200 feet in length, excluding

heliports and seaplane bases without specified boundaries, if that airport is either listed in the Airport Directory or is operated by a Federal military agency.

(iii) 25 to 1 for a horizontal distance of 5,000 feet from the nearest point of the nearest landing and takeoff area of each heliport listed in the Airport Directory or operated by a Federal miliary agency.

(3) Any construction or alteration on an airport listed in the Airport Directory of the Airman's Information Manual (17.7(c) of this chapter).

(b) A notification to the Federal Aviation Administration is not required for any of the following construction or alteration:

(1) Any object that would be shielded by existing structures of a permanent and substantial character or by natural terrain or topographic features of equal or greater height, and would be located in the congested area of a city, town, or settlement where it is evident beyond all reasonable doubt that the structure so shielded will not adversely affect safety in air navigation. Applicants claiming such exemption shall submit a statement with their application to the Commission explaining the basis in detail for their finding (17.14(a) of this chapter).

(2) Any antenna structure of 20 feet or less in height except one that would increase the height of another antenna structure (17.14(b) of this chapter).

(c) Further details as to whether an aeronautical study and/or obstruction marking and lighting may be required, and specifications for obstruction marking and lighting when required, may be obtained from Part 17 of this chapter, "Construction, Marking, and Lighting of Antenna Structures." Information regarding the inspection and maintenance of antenna structures requiring obstruction marking and lighting is also contained in Part 17 of this chapter.

# Appendix C

# Tables and Nomograms

**NATURAL TRIGONOMETRIC FUNCTIONS**

| Angle | Sine | Cosine | Tangent | Angle | Sine | Cosine | Tangent |
|---|---|---|---|---|---|---|---|
| 0° | 0.000 | 1.000 | 0.000 | 46° | .719 | .695 | 1.036 |
| 1° | .018 | 1.000 | .018 | 47° | .731 | .682 | 1.072 |
| 2° | .035 | 0.999 | .035 | 48° | .743 | .669 | 1.111 |
| 3° | .052 | .999 | .052 | 49° | .755 | .656 | 1.150 |
| 4° | .707 | .998 | .707 | 50° | .766 | .643 | 1.192 |
| 5° | .087 | .996 | .088 | 50° | 766 | .643 | 1.192 |
| 6° | .105 | .995 | .105 | 51° | .777 | .629 | 1.235 |
| 7° | .122 | .993 | | | | | .123 |
| 8° | .139 | .990 | .141 | 53° | .799 | .602 | 1.327 |
| 9° | .156 | .988 | .158 | 54° | .809 | .588 | 1.376 |
| 10° | .174 | .985 | .176 | 55° | .819 | .574 | 1.428 |
| 11° | .191 | .982 | .194 | 56° | .829 | .559 | 1.483 |
| 12° | .208 | .978 | .213 | 57° | .839 | .545 | 1.540 |
| 13° | .225 | .974 | .231 | 58° | .848 | .530 | 1.600 |
| 14° | .242 | .970 | .249 | 59° | .857 | .515 | 1.664 |
| 15° | .259 | .966 | .268 | 60° | .866 | .500 | 1.732 |
| 16° | .276 | .961 | .287 | 61° | .875 | .485 | 1.804 |
| 17° | .292 | .956 | .306 | 62° | .883 | .470 | 1.881 |
| 18° | .309 | .951 | .325 | 63° | .891 | .454 | 1.963 |
| 19° | .326 | .946 | .344 | 64° | .899 | .438 | 2 050 |
| 20° | .342 | .940 | .364 | 65° | .906 | .423 | 2.144 |
| 21° | .358 | .934. | .384 | 66° | .914 | .497 | 2.246 |
| 22° | .375 | .927 | .404 | 67° | .921 | .391 | 2.356 |
| 23° | .291 | .921 | .424 | 68° | .927 | .375 | 2.475 |
| 24° | .407 | .914 | .445 | 69° | .934 | .358 | 2.605 |
| 25° | .423 | .906 | .466 | 70° | .940 | .342 | 2.748 |
| 26° | .438 | .899 | .488 | 71° | .946 | .326 | 2.904 |
| 27° | .454 | .891 | .510 | 72° | .951 | .309 | 3.078 |
| 28° | .470 | .883 | .532 | 73° | .956 | .291 | 3.217 |
| 29° | .485 | .875 | .554 | 74° | .961 | .276 | 3.487 |
| 30° | .500 | .866 | .577 | 75° | .966 | .259 | 3.732 |
| 31° | .515 | .857 | .601 | 76° | .970 | .242 | 4.011 |
| 32° | 530 | .848 | .625 | 77° | .974 | .225 | 4.332 |
| 33° | .454 | .839 | .649 | 78° | .978 | .208 | 4.705 |
| 34° | .559 | .829 | .674 | 79 | .982 | .191 | 5.145 |
| 35° | .574 | .819 | .700 | 80° | .985 | .174 | 5.671 |
| 36° | .588 | .809 | .727 | 81° | .988 | .156 | 6.314 |
| 37° | .602 | .799 | .754 | 82° | .990 | .130 | 7.115 |
| 38° | .616 | .788 | .718 | 83° | .993 | .122 | 8.144 |
| 39° | .629 | .777 | .810 | 84° | .995 | .105 | 9.514 |
| 40° | .643 | .766 | .839 | 85° | .996 | .087 | 11.430 |
| 41° | .656 | .755 | .869 | 86° | .998 | .070 | 14.301 |
| 42° | .669 | .743 | .900 | 87° | .999 | .052 | 19.081 |
| 43° | .682 | .731 | .933 | 88° | .999 | .035 | 28.363 |
| 44° | .695 | .719 | .966 | 89° | 1.000 | .018 | 57.290 |
| 45° | .707 | .707 | 1.000 | 90° | 1.000 | .000 | |

These are the more commonly used logarithms, and should not be confused with the *natural* logarithms.

To find the $\log_{10}$ of a number, first set down the number of digits to the left of the decimal point less one. Then, using those same digits, determine the four-digit number from the table and put those four digits to the right of a decimal.

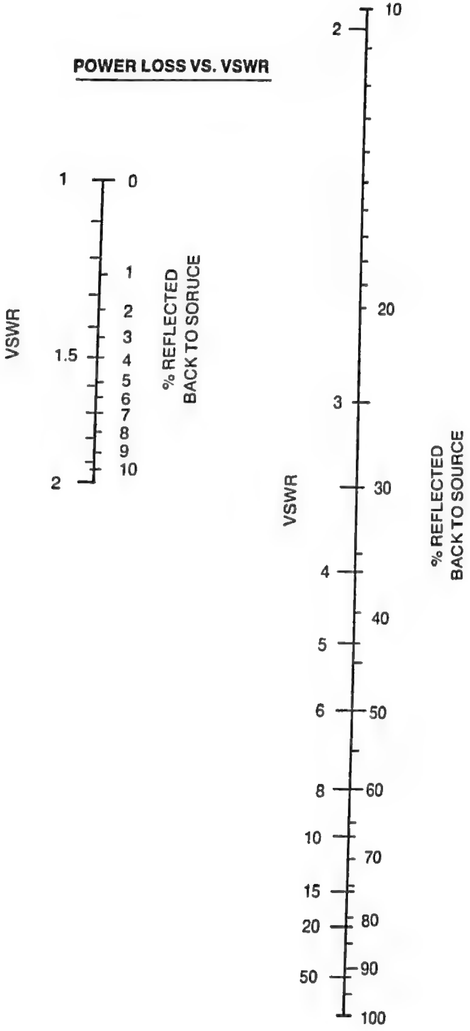
| N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0000 | 0043 | 0086 | 0128 | 0170 | 0212 | 0253 | 0294 | 0334 | 0374 |
| 11 | 0414 | 0453 | 0492 | 0531 | 0569 | 0697 | 0645 | 0582 | 0719 | 0755 |
| 12 | 0792 | 0828 | 0864 | 0899 | 0934 | 0969 | 1004 | 1038 | 1072 | 1106 |
| 13 | 1139 | 1173 | 1206 | 1239 | 1271 | 1303 | 1335 | 1367 | 1399 | 1430 |
| 14 | 1461 | 1492 | 1523 | 1553 | 1584 | 1614 | 1644 | 1673 | 1703 | 1732 |
| 15 | 1761 | 1790 | 1818 | 1847 | 1875 | 1903 | 1931 | 1959 | 1987 | 2014 |
| 16 | 2041 | 2068 | 2095 | 2122 | 2148 | 2175 | 2201 | 2227 | 2253 | 2279 |
| 17 | 2304 | 2330 | 2355 | 2380 | 2405 | 2430 | 2455 | 2480 | 2504 | 2529 |
| 18 | 2553 | 2577 | 2601 | 2625 | 2648 | 2672 | 2695 | 2718 | 2742 | 2765 |
| 19 | 2788 | 2810 | 2833 | 2856 | 2878 | 2900 | 2923 | 2945 | 2967 | 2989 |
| 20 | 3010 | 3032 | 3054 | 3075 | 3096 | 3118 | 3139 | 3160 | 3181 | 3201 |
| 21 | 3222 | 3243 | 3263 | 3284 | 3304 | 3324 | 3345 | 3365 | 3385 | 3404 |
| 22 | 3424 | 3444 | 3464 | 3483 | 3502 | 3522 | 3541 | 3560 | 3579 | 3598 |
| 23 | 3617 | 3636 | 3655 | 3674 | 3692 | 3711 | 3729 | 3747 | 3766 | 3784 |
| 24 | 3802 | 3820 | 3838 | 3856 | 3874 | 3892 | 3909 | 3927 | 3945 | 3962 |
| 25 | 3979 | 3997 | 4014 | 4031 | 4048 | 4065 | 4082 | 4099 | 4116 | 4133 |
| 26 | 4150 | 4166 | 4183 | 4200 | 4216 | 4232 | 4249 | 4265 | 4281 | 4298 |
| 27 | 4314 | 4330 | 4346 | 4362 | 4378 | 4393 | 4409 | 4425 | 4440 | 4456 |
| 28 | 4472 | 4487 | 4502 | 4518 | 4533 | 4548 | 4564 | 4579 | 4594 | 4609 |
| 29 | 4624 | 2639 | 4654 | 4669 | 4683 | 3698 | 4713 | 3728 | 2742 | 2757 |
| 30 | 4771 | 4786 | 4800 | 4814 | 4829 | 4843 | 4857 | 4871 | 4868 | 4900 |
| 31 | 3914 | 4928 | 4942 | 4955 | 5969 | 4983 | 4997 | 5011 | 5024 | 5038 |
| 32 | 5051 | 5065 | 5079 | 5092 | 5105 | 5119 | 5132 | 5145 | 5159 | 5172 |
| 33 | 5185 | 5198 | 5211 | 5224 | 5237 | 5250 | 5263 | 5276 | 5289 | 5302 |
| 34 | 5315 | 5238 | 5340 | 5353 | 5366 | 5378 | 5391 | 5403 | 5416 | 5238 |
| 35 | 5441 | 5453 | 5465 | 5478 | 5490 | 5502 | 5514 | 5527 | 5539 | 5551 |
| 36 | 5563 | 5575 | 5587 | 5599 | 5611 | 5623 | 5635 | 5647 | 5658 | 5670 |
| 37 | 5682 | 5694 | 5705 | 5717 | 5729 | 5740 | 5752 | 5763 | 5775 | 5786 |
| 38 | 5798 | 5809 | 5821 | 5832 | 5843 | 5855 | 5866 | 5877 | 5888 | 5899 |
| 39 | 5911 | 5922 | 5933 | 5944 | 5955 | 5966 | 5977 | 5988 | 5999 | 6010 |
| 40 | 6021 | 6031 | 6042 | 6053 | 6064 | 6075 | 6085 | 6096 | 6107 | 6117 |
| 41 | 6128 | 6138 | 6149 | 6160 | 6170 | 6180 | 6191 | 6201 | 6212 | 6222 |
| 42 | 6232 | 6243 | 6253 | 6263 | 6274 | 6284 | 6294 | 6304 | 6314 | 6325 |
| 43 | 6335 | 6345 | 6355 | 6365 | 6375 | 6385 | 6395 | 6405 | 6415 | 6425 |
| 44 | 6435 | 6444 | 6454 | 6464 | 6474 | 6484 | 6493 | 6503 | 6513 | 6522 |
| 45 | 6532 | 6542 | 6551 | 6561 | 6571 | 6580 | 6590 | 6599 | 6609 | 6618 |
| 46 | 6628 | 6637 | 6646 | 6656 | 6665 | 6675 | 6684 | 6693 | 6702 | 6712 |
| 47 | 6721 | 6730 | 6739 | 6749 | 6758 | 6767 | 6776 | 6785 | 6794 | 6803 |
| 48 | 6812 | 6821 | 6830 | 6839 | 6848 | 6857 | 6866 | 6875 | 6884 | 6893 |
| 49 | 6902 | 6911 | 6920 | 6928 | 6937 | 6946 | 6955 | 6964 | 6972 | 6981 |
| 50 | 6990 | 6997 | 7007 | 7016 | 7024 | 7033 | 7042 | 7050 | 7059 | 7067 |
| 51 | 7076 | 7084 | 7093 | 7101 | 7110 | 7118 | 7126 | 7135 | 7143 | 7152 |
| 52 | 7160 | 7168 | 7177 | 7185 | 7193 | 7202 | 7210 | 7218 | 7226 | 7235 |
| 53 | 7243 | 7251 | 7259 | 7267 | 7275 | 7284 | 7292 | 7300 | 7308 | 7316 |
| 54 | 7324 | 7332 | 7340 | 7348 | 7356 | 7364 | 7372 | 7380 | 7388 | 7396 |
| N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

For example, the log of 165:
165 has three digits to the left of the decimal.
We put down a number 2

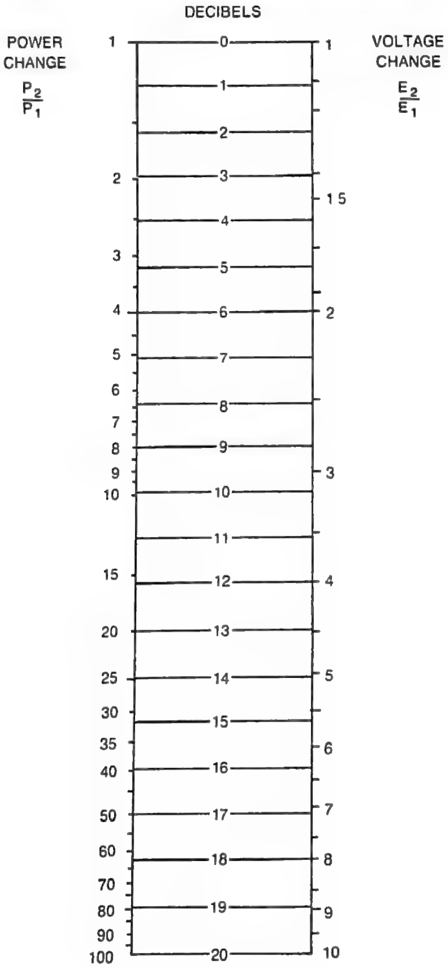
From the table, 16, (the first two digits) in the vertical column, then 5 (the third digit) in the horizontal column, we get 2175.

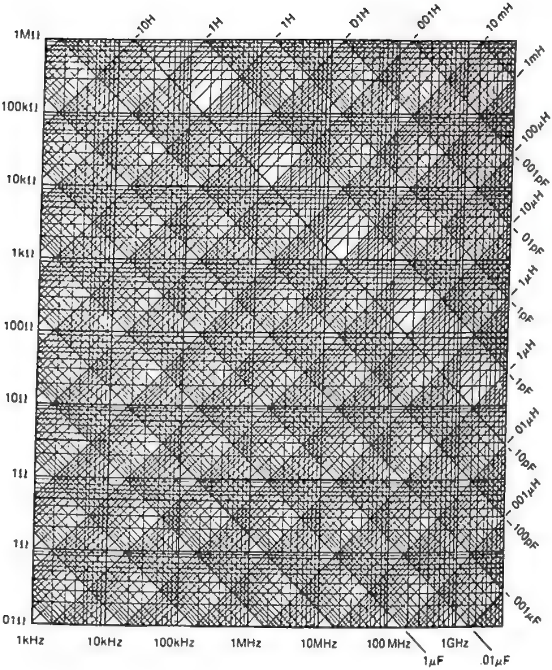
| N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 55 | 7404 | 7412 | 7419 | 7427 | 7425 | 7443 | 7451 | 7459 | 7466 | 7474 |
| 56 | 7482 | 7490 | 7497 | 7505 | 7513 | 7520 | 7528 | 7536 | 7543 | 7551 |
| 57 | 7559 | 7566 | 7574 | 7582 | 7589 | 7597 | 7604 | 7612 | 7619 | 7627 |
| 58 | 7634 | 7642 | 7649 | 7657 | 7664 | 7672 | 7679 | 7685 | 7694 | 7701 |
| 59 | 7709 | 7716 | 7723 | 7731 | 7738 | 7745 | 7752 | 7760 | 7767 | 7774 |
| 60 | 7782 | 7789 | 7796 | 7803 | 7810 | 7818 | 7825 | 7832 | 7839 | 7846 |
| 61 | 7853 | 7860 | 7868 | 7875 | 7882 | 7889 | 7896 | 7903 | 7910 | 7917 |
| 62 | 7924 | 7931 | 7938 | 7945 | 7952 | 7959 | 7966 | 7973 | 7980 | 7987 |
| 63 | 7993 | 8000 | 8007 | 8014 | 8021 | 8028 | 8035 | 8041 | 8048 | 8055 |
| 64 | 8062 | 8069 | 8075 | 8082 | 8089 | 8096 | 8102 | 8109 | 8116 | 8122 |
| 65 | 8129 | 8136 | 8142 | 8149 | 8156 | 8162 | 8169 | 8176 | 8182 | 8189 |
| 66 | 8195 | 8202 | 8209 | 8215 | 8222 | 8228 | 8235 | 8241 | 8248 | 8254 |
| 67 | 8261 | 8267 | 8274 | 8280 | 8287 | 8293 | 8299 | 8306 | 9312 | 8319 |
| 68 | 8325 | 8331 | 8338 | 8344 | 8351 | 8357 | 8363 | 8370 | 8376 | 8382 |
| 69 | 8388 | 8395 | 8401 | 8407 | 8414 | 8420 | 8426 | 8432 | 8439 | 8445 |
| 70 | 8451 | 8457 | 8463 | 8470 | 8476 | 8482 | 8488 | 8494 | 8500 | 8506 |
| 71 | 8513 | 8519 | 8525 | 8531 | 8537 | 8543 | 8549 | 8555 | 8561 | 8567 |
| 72 | 8573 | 8579 | 8585 | 8591 | 8597 | 8603 | 8609 | 8615 | 8621 | 8627 |
| 73 | 8633 | 8639 | 8645 | 8651 | 8657 | 8663 | 8669 | 8675 | 8681 | 8686 |
| 74 | 8692 | 8698 | 8704 | 8710 | 8716 | 8722 | 8727 | 8733 | 8739 | 8745 |
| 75 | 8751 | 8756 | 8762 | 8768 | 8774 | 8779 | 8785 | 8791 | 8797 | 8802 |
| 76 | 8808 | 8814 | 8820 | 8825 | 8831 | 8837 | 8842 | 8848 | 8854 | 8859 |
| 77 | 8865 | 8871 | 8876 | 8882 | 8887 | 8803 | 8899 | 8904 | 8910 | 8915 |
| 78 | 8921 | 8927 | 8932 | 8938 | 8943 | 8949 | 8954 | 8960 | 8965 | 8971 |
| 79 | 8976 | 8982 | 8987 | 8993 | 8998 | 9004 | 9009 | 9015 | 9020 | 9025 |
| 80 | 9131 | 9036 | 9042 | 9047 | 9053 | 9058 | 9063 | 9069 | 9074 | 9079 |
| 81 | 9085 | 9090 | 9096 | 9101 | 9106 | 9112 | 9117 | 9122 | 9128 | 9133 |
| 82 | 9138 | 9143 | 9149 | 9154 | 9159 | 9165 | 9170 | 9175 | 9180 | 9186 |
| 83 | 9191 | 9196 | 9201 | 9206 | 9212 | 9217 | 9222 | 9227 | 9232 | 9238 |
| 84 | 9243 | 9248 | 9253 | 9258 | 9263 | 9269 | 9274 | 9279 | 9284 | 9289 |
| 85 | 9294 | 9299 | 9304 | 9309 | 9315 | 9320 | 9325 | 9330 | 9335 | 9340 |
| 86 | 9345 | 9350 | 9355 | 9360 | 9365 | 9370 | 9375 | 9380 | 9385 | 9390 |
| 87 | 9395 | 9400 | 9405 | 9410 | 9415 | 9420 | 9425 | 9439 | 9435 | 9440 |
| 88 | 9445 | 9450 | 9455 | 9460 | 9465 | 9469 | 9474 | 9479 | 9484 | 9489 |
| 89 | 9494 | 9499 | 9504 | 9509 | 9513 | 9518 | 9523 | 9528 | 9533 | 9538 |
| 90 | 9542 | 9547 | 9552 | 9557 | 9562 | 9566 | 9571 | 9576 | 9581 | 9586 |
| 91 | 9590 | 95959 | 9600 | 9605 | 9609 | 9614 | 9619 | 9624 | 9628 | 9633 |
| 92 | 9638 | 9643 | 9647 | 9652 | 9657 | 9661 | 9666 | 9671 | 9675 | 9680 |
| 93 | 9685 | 9680 | 9694 | 9699 | 9703 | 9708 | 9713 | 9717 | 9722 | 9727 |
| 94 | 9731 | 9736 | 9741 | 9745 | 9750 | 9754 | 9759 | 9763 | 9768 | 9773 |
| 95 | 9777 | 9782 | 9786 | 9791 | 9795 | 9800 | 9805 | 9809 | 9814 | 9813 |
| 96 | 9823 | 9827 | 9832 | 9836 | 9841 | 9845 | 9850 | 9854 | 9859 | 9863 |
| 97 | 9868 | 9872 | 9877 | 9881 | 9886 | 9890 | 9894 | 9899 | 9903 | 9908 |
| 98 | 9912 | 9917 | 9921 | 9926 | 9930 | 9934 | 9939 | 9943 | 9948 | 9952 |
| 99 | 9956 | 9961 | 9965 | 9969 | 9974 | 9978 | 9983 | 9987 | 9991 | 9996 |
| N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

## POWER LOSS VS. VSWR



## DECIBEL VS. POWER AND VOLTAGE RATIOS






**RESISTANCE/CAPACITANCE/INDUCTANCE NOMOGRAM**

# Appendix D

# Where to Get the Goodies

Antenna systems are perhaps the last stronghold of amateur home-brewing. Within the last decade or so, especially since CB came into its own, home-brew equipment seems to have lost much of its popularity. Part of this is due to the increasing difficulty of obtaining parts. More and more distributors seem to be dropping a lot of the more vital parts lines in favor of faster-moving merchandise.

In this section, we will list some (but not necessarily all) of the manufacturers of needed materials. You can either order specific parts directly from the manufacturer, or the manufacturer will gladly put you in touch with a local distributor.

ANTENNAS, High Frequency

Antenna Supermarket
P.O. Box 1682
Largo, Florida 33540

Cush Craft
621 Hayward St.
Manchester, N.H. 03103

Antenna Specialists
12435 Euclid Ave.
Cleveland, Ohio 44106

ANTENNAS, VHF & UHF

Cush Craft (Address previously listed)

Hy-Gain Electronics Corp.
8601 Northeast Highway 6
Lincoln, Nebraska 68505

Telrex Labs
Asbury Park, N.J. 07712

ANTENNAS, Mobile

New-tronics Corp. (Hustler)
15800 Commerce Park Drive
Brookpark, Ohio 44142

Premax Products Div.
Chisholm-Ryder Co., Inc.
College & Highland Aves.
Niagara Falls, N.Y., 14305

Barker & Williamson
(Address listed under "INDUCTORS")

ANTENNA COUPLERS
Barker & Williamson
(Address listed under "INDUCTORS")

R.L. Drake
(Address listed under "FILTERS")

Dentron Radio Company
2100 Enterprise Parkway
Twinsburg, Ohio, 44087

COAXIAL SWITCHES
Barker & Williamson
(Address listed under "INDUCTORS")

Heath Company
Benton Harbor
Michigan 49022

DUMMY ANTENNAS
Heath Company
Benton Harbor
Michigan 49022

DIP WAVE METERS
James Millen Manufacturing Company
150 Exchange Street
Malden, Mass., 02148

Heath Company
(Address listed previously)

FIELD STRENGTH METERS
REFLECTED POWER METERS
RF WATTMETERS
R.L. Drake
(Address listed under "FILTERS")

Heath Company
(Address previously listed)

FILTERS, TVI
R.L. Drake
540 Richard Street
Miamisburg, Ohio 45342

Radio Shack

INDUCTORS, FERRITE
CORE VARIABLE
J.W. Miller Division
Bell Industries
19070 Reyes Ave.
P.O. Box 5825
Compton, Cal., 90224

INDUCTORS, AIR CORE
Barker & Williamson, Inc.
Canal Street
Bristol, PA., 19007

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VARIABLE CAPACITORS

The major lines of Variable Capacitors, Johnson, National, and Cardwell are all being produced by

Cardwell Condenser Corp.
80E Montauk Hwy.
Lindenhurst, L.I., N.Y. 11757

Cardwell informed me that they are in the process of organizing to handle individual, single-item orders.

James Millen distributor list

Small components can be ordered from:

G.R. Whitehouse & Co.
Newbury Drive
Amherst, H.H., 03031
603-673-6290

# Index

# HOME-BREW HF/VHF ANTENNA HANDBOOK

From exotic "hidden" and restricted-space antennas to "farms" of vertical towers, stacked beam arrays and long-wires, here is everything you've ever wanted to know about antennas! A complete handbook for hams, CBers, mobile operators, and SWLs, a build-it or adapt-it-yourself guide for those who want optimum performance on both receiving and transmitting.

- ☐ Design or adapt and install full wave, half wave, and quarter wave long-wires, half-wave dipoles, phased and directional antennas.
- ☐ Solve "visibility" and space problems in restricted neighborhoods with antennas that look like a fence; squeeze a half wavelength of wire into a few feet.
- ☐ Get the best results with mobile antennas; various types are suggested.
- ☐ Master the techniques of tuning, pruning and matching.
- ☐ Cure television interference.
- ☐ Avoid lightning damage: install adequate protection.
- ☐ Make, buy, and use dummy antennas, SWR meters, dip wavemeters, field-strength meters, impedance bridges.

The author, a 25-year veteran in ham radio, joined the amateur ranks in 1952 (WN1USM) and has worked professionally in electronics since 1956. He has written numerous articles for "73" and "CQ" magazines. Mr. Hood moved from his native Boston in 1969 to Rochester, N.Y., where he is employed by Scientific Radio Systems. He presently holds an Amateur Extra Class license and a First Class Radiotelephone license.



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